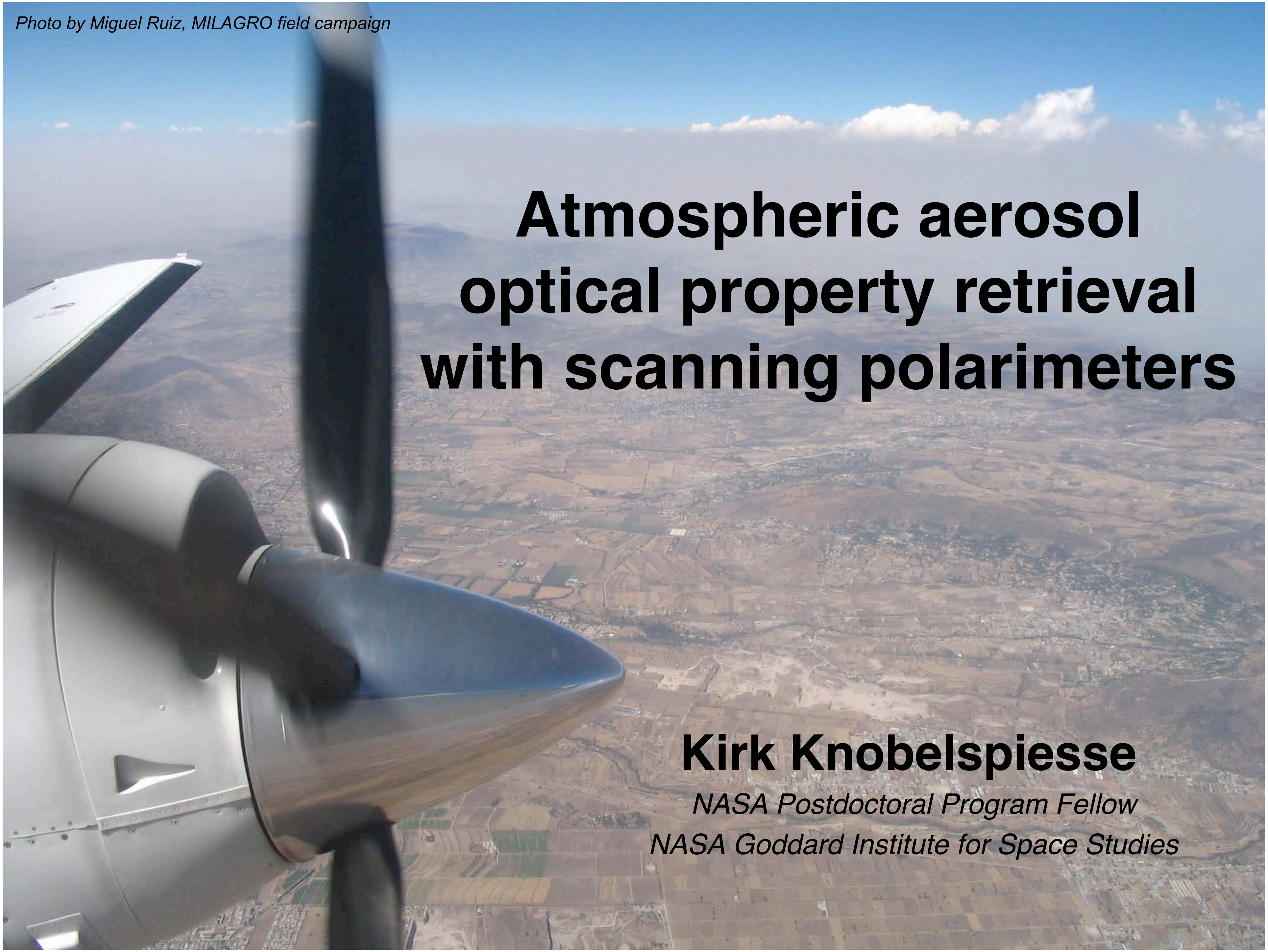


Photo by Miguel Ruiz, MILAGRO field campaign

Atmospheric aerosol optical property retrieval with scanning polarimeters

Kirk Knobelspiesse

NASA Postdoctoral Program Fellow

NASA Goddard Institute for Space Studies

Outline

(abridged thesis defense)

Aerosols, remote sensing, and scanning polarimeters

Aerosol property retrieval

- Doubling and Adding Optimization (DAO)

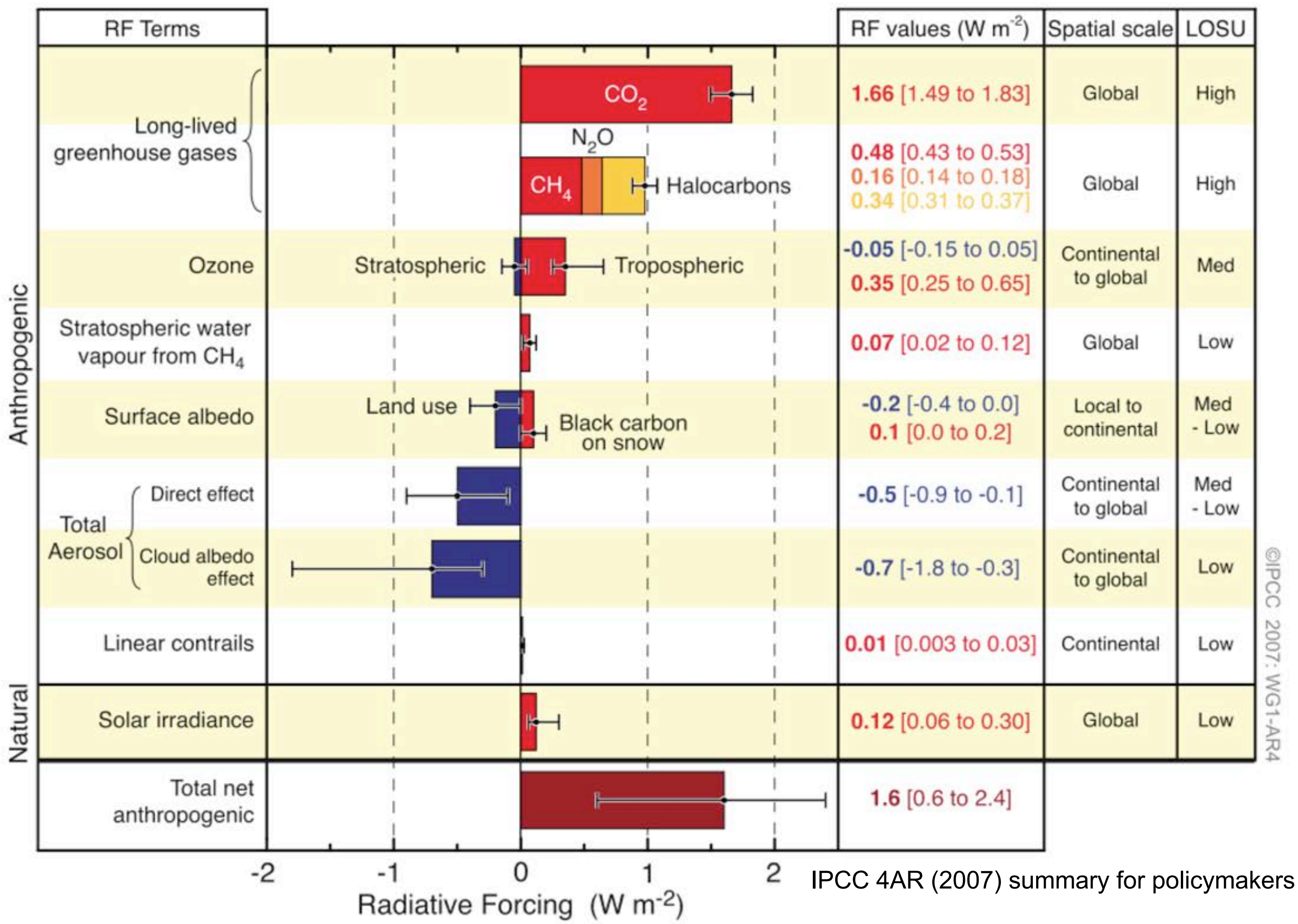
Investigation of scanning polarimeter capability with DAO

- **ARCTAS -** *"Combined retrievals of boreal forest fire aerosol properties with a Polarimeter and a Lidar"*
- **MILAGRO -** *"Simultaneous retrieval of aerosol and cloud properties during the MILAGRO field campaign"*

Conclusions

Future Work

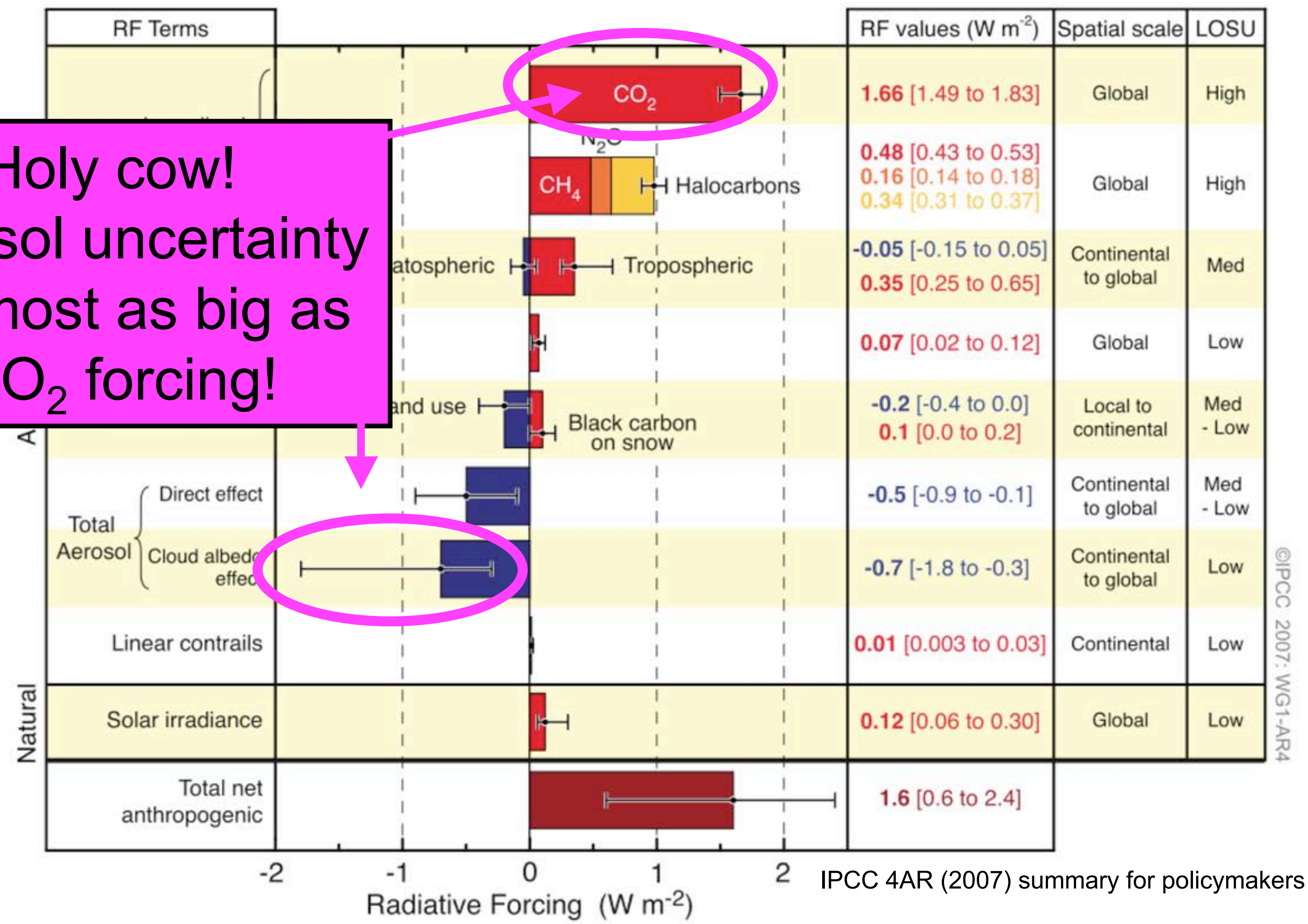
Motivation: aerosol climate uncertainty



IPCC 4AR (2007) summary for policymakers

Motivation: aerosol climate uncertainty

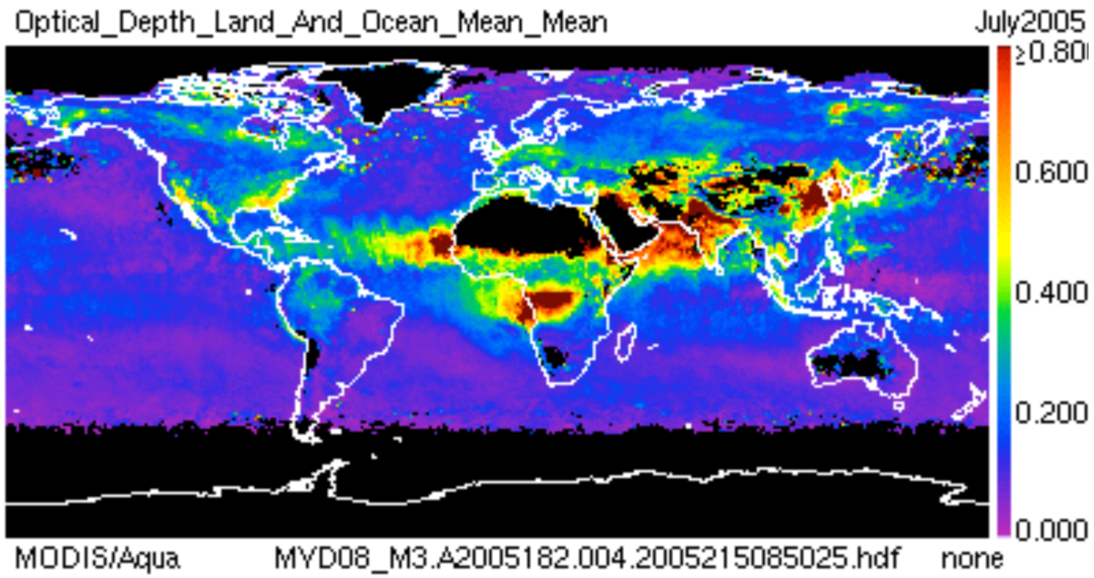
Holy cow!
Aerosol uncertainty is almost as big as CO_2 forcing!



IPCC 4AR (2007) summary for policymakers

Why are aerosols so difficult?

They are regional and heterogeneous

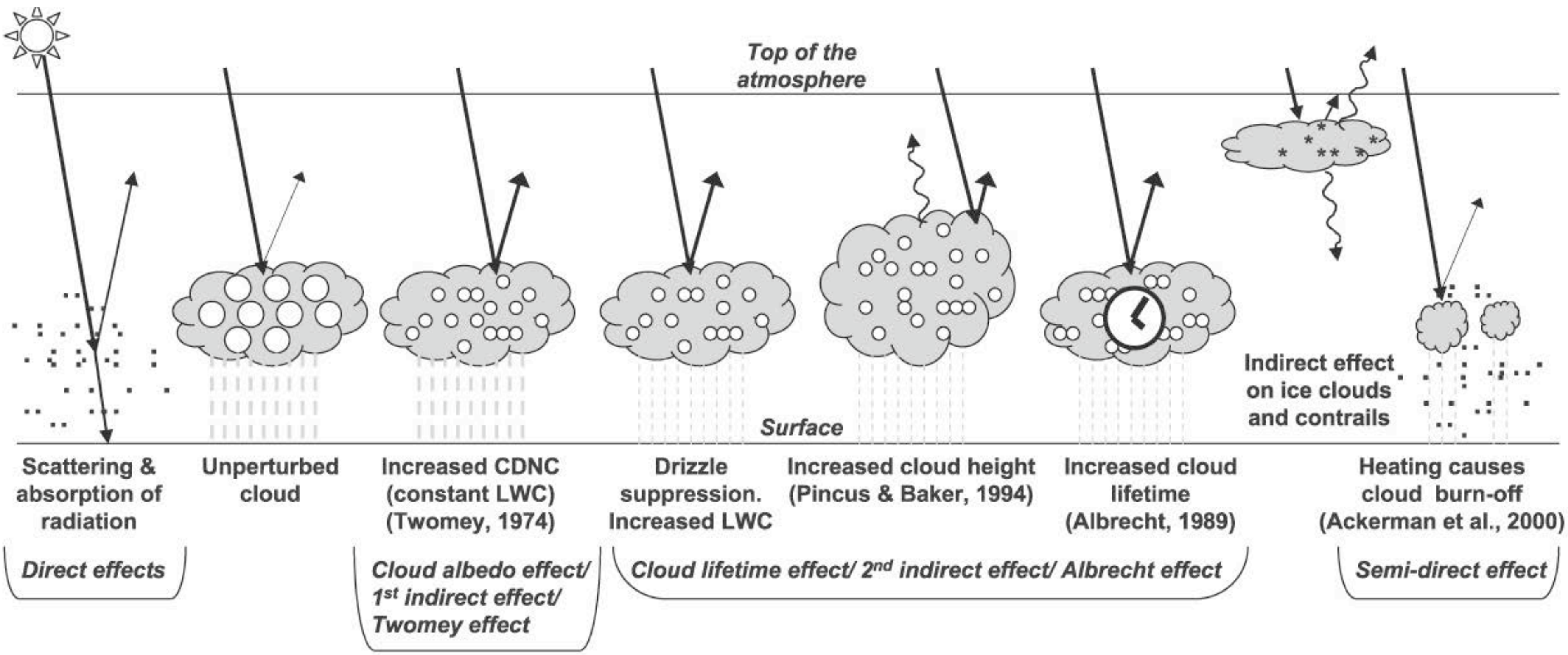


MODIS-Atmosphere Project, NASA/Goddard Space Flight Center

NASA image courtesy of Jeff Schmaltz, MODIS Rapid Response Team, NASA-Goddard Space Flight Center

Why are aerosols so difficult?

They interact with climate in many complicated ways



IPCC Fourth Assessment Report, 2007. Figure 2.10

Aerosols are not well understood

Even with same data, forcing estimates vary

- N. Bellouin, et al. Nature, 2005: -1.9 ± 0.3 Wm^{-2}
- C.E. Chung, et al. J Geophys Res, 2005: -3.4 ± 0.1 Wm^{-2}

Aerosol observation are often underdetermined. Models need *

- Aerosol optical thickness
- Aerosol size & refractive index
- Nonsphericity
- Cloud/aerosol interactions

Next generation of aerosol remote sensing: scanning polarimeters

*M. Mishchenko, B. Cairns, J. Hansen, L. Travis, R. Burg, Y. Kaufman, J. Vanderlei Martins, and E. Shettle. Monitoring of aerosol forcing of climate from space: analysis of measurement requirements. *J. Quant. Spectrosc. Radiat. Transfer*, 88(1-3):149–161, 2004.

Scanning Polarimeters

Research Scanning Polarimeter (RSP)

Airborne prototype of APS, similar properties

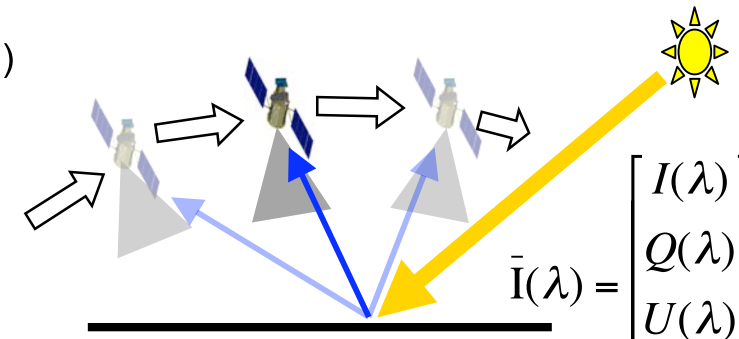
Aerosol Polarimetry Sensor (APS)

February 23rd launch date as part of NASA Glory mission

RSP and APS

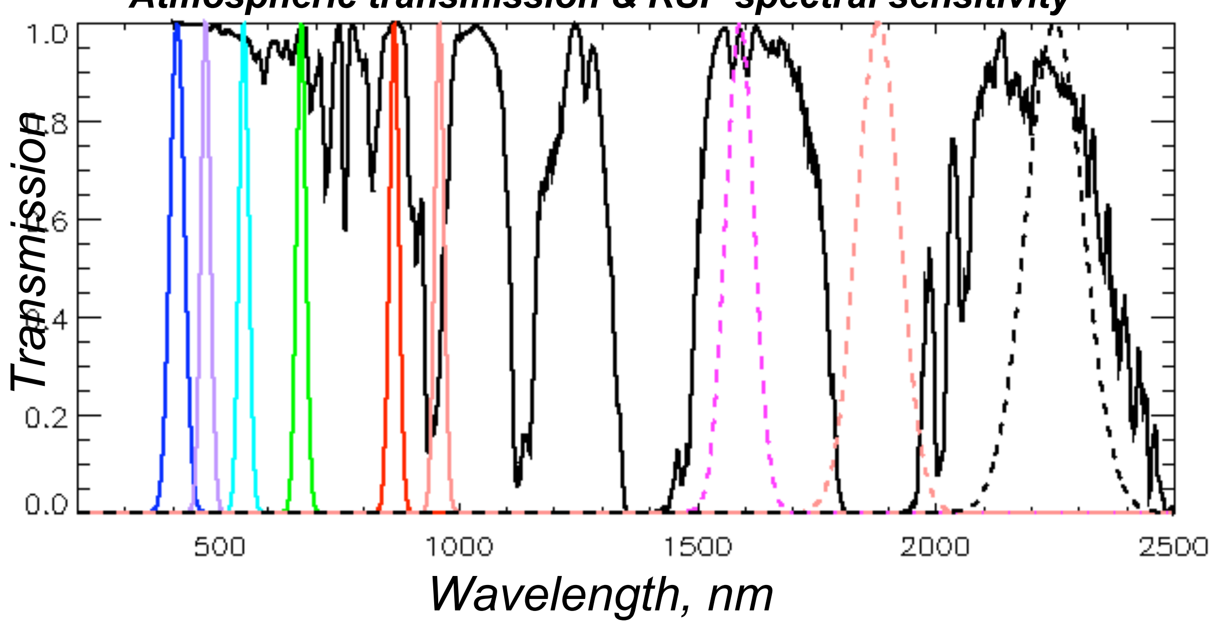
Ideal for aerosol, cloud property retrieval

- Nine spectral channels, blue to infra-red (410 - 2250 nm)
- Scans along track (in the direction of motion)
- Polarized radiance - I,Q,U components of Stokes vector
- High (0.2%) accuracy for polarized radiances



$$\bar{I}(\lambda) = \begin{bmatrix} I(\lambda) \\ Q(\lambda) \\ U(\lambda) \\ \cancel{V(\lambda)} \end{bmatrix}$$

Atmospheric transmission & RSP spectral sensitivity



RSP Aerosol channels:
410nm, 470nm, 555nm, 670nm, 865nm, 1590nm

RSO Other Channels:
960nm, 1880nm, 2250nm

Stokes Vectors

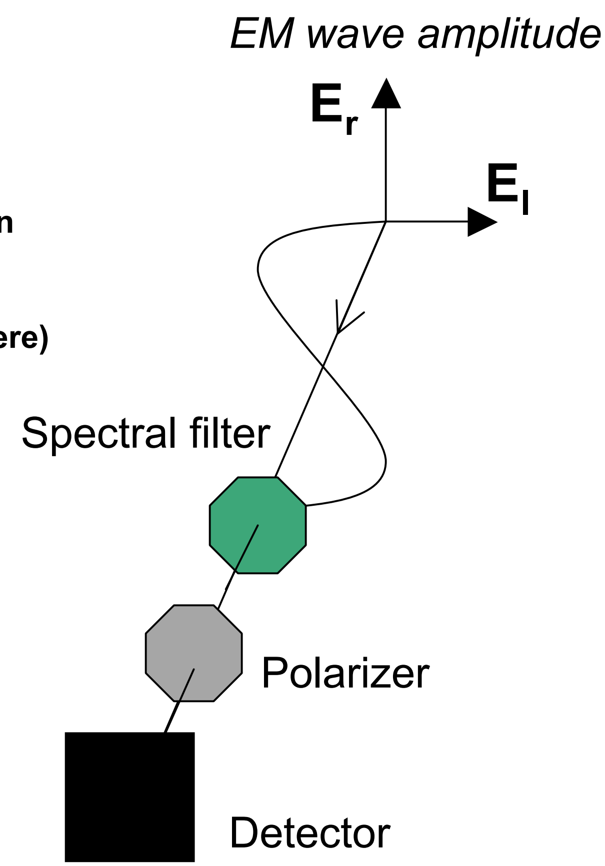
Polarization described by Stokes vectors

$$\bar{I} = \begin{bmatrix} I \\ Q \\ U \\ \cancel{V} \end{bmatrix} = \begin{bmatrix} \langle E_l E_l^* + E_r E_r^* \rangle \\ \langle E_l E_l^* - E_r E_r^* \rangle \\ \langle E_l E_r^* + E_r E_l^* \rangle \\ \cancel{-i\langle E_l E_r^* - E_r E_l^* \rangle} \end{bmatrix}$$

Total intensity

Direction and magnitude of linear polarization

Circular Polarization (neglected for atmosphere)



I typically use reflectance units (can be negative!)

$$\begin{bmatrix} R_I \\ R_Q \\ R_U \\ \cancel{R_V} \end{bmatrix} = \frac{r_o^2 \pi}{F_o \cos\theta_s} \begin{bmatrix} I \\ Q \\ U \\ \cancel{V} \end{bmatrix}$$

(linearly) polarized reflectance

$$R_p = \sqrt{R_Q^2 + R_U^2}$$

(independent of E_r and E_l reference frame, but bounded at zero)

r_o - solar distance [AU]
F_o - annual average exo-atmospheric irradiance [W/m^2]
θ_s - Solar zenith angle [degrees]

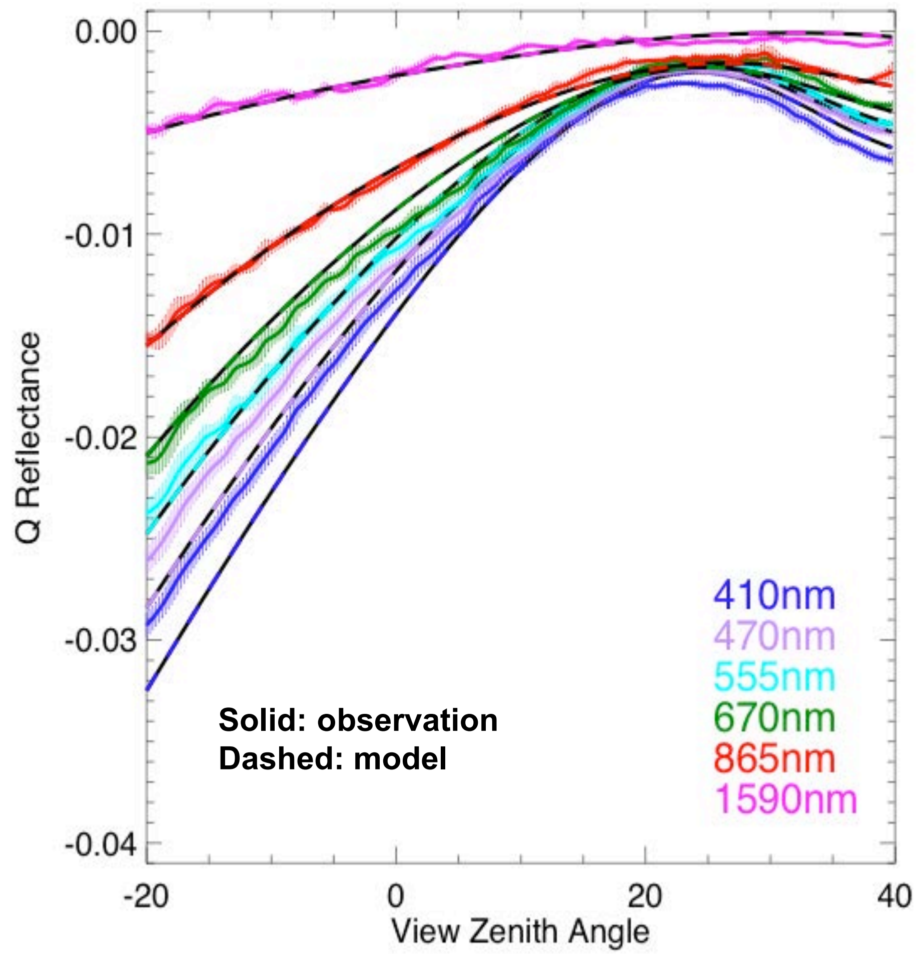
Aerosol Retrievals

A radiative transfer model is tuned to match observations

Aerosol parameters that give the best match are the 'retrieved' values

What do we retrieve?

Boreal forest fire smoke, Canada



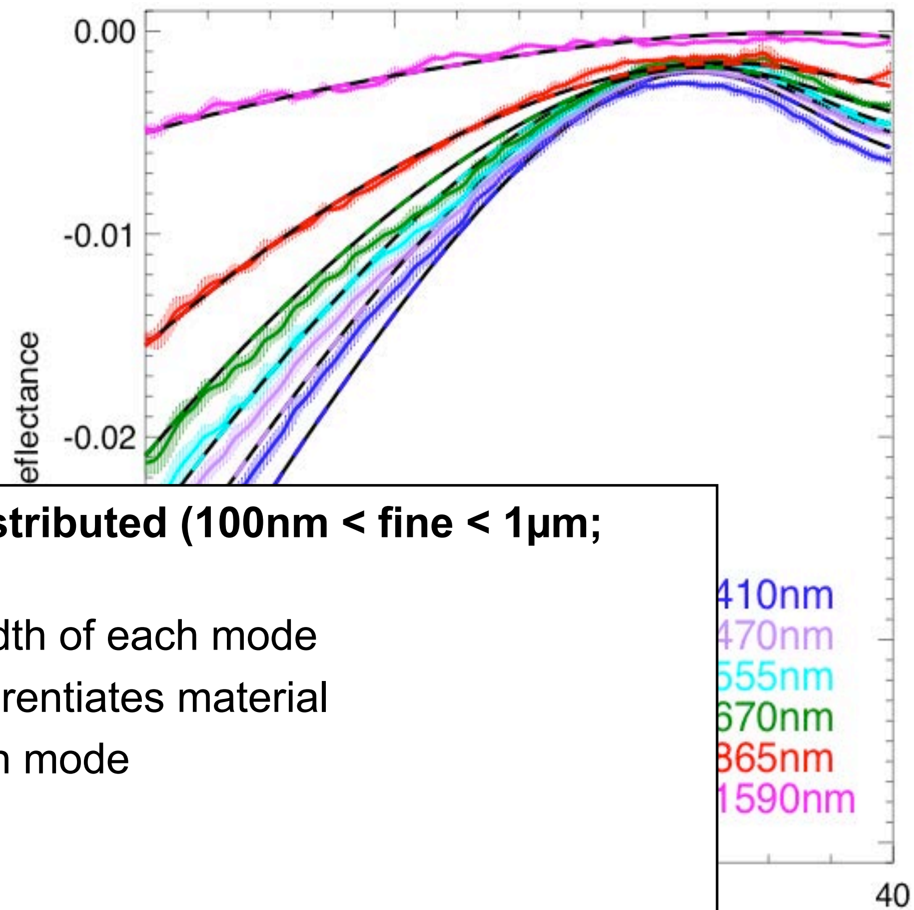
Aerosol Retrievals

A radiative transfer model is tuned to match observations

Aerosol parameters that give the best match are the 'retrieved' values

What do we retrieve?

Boreal forest fire smoke, Canada



Aerosols are generally bimodally distributed (100nm < fine < 1µm; coarse > 1µm)

- **Size distribution**: mean and width of each mode
- **Complex refractive index**: differentiates material
- **Number concentration:** of each mode

From this we derive other values

- **Aerosol Optical Thickness:** total column attenuation
- **Single Scattering Albedo:** ratio of scattering to total extinction

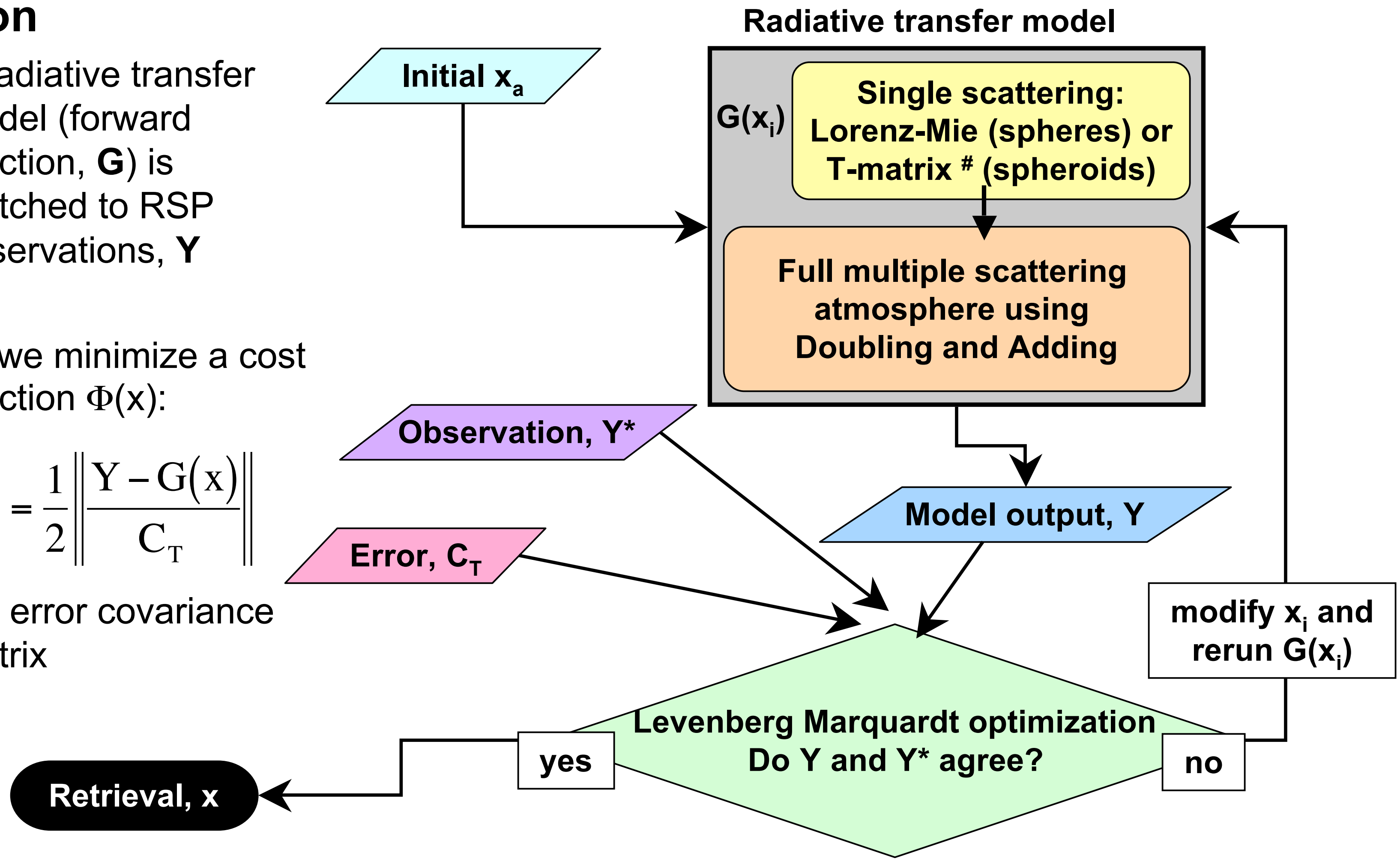
Optimal Estimation

Inversion

- A radiative transfer model (forward function, **G**) is matched to RSP observations, **Y**
- ie. we minimize a cost function $\Phi(x)$:

$$\Phi(x) = \frac{1}{2}\left\| \frac{Y - G(x)}{C_T} \right\|$$

- C_T: error covariance matrix



see: M. Mishchenko, L. Travis, and D. Mackowski. T-Matrix Computations of Light Scattering by Nonspherical Particles: a Review. *Journal of quantitative spectroscopy & radiative transfer*, 55(5), 1996.

Optimal Estimation

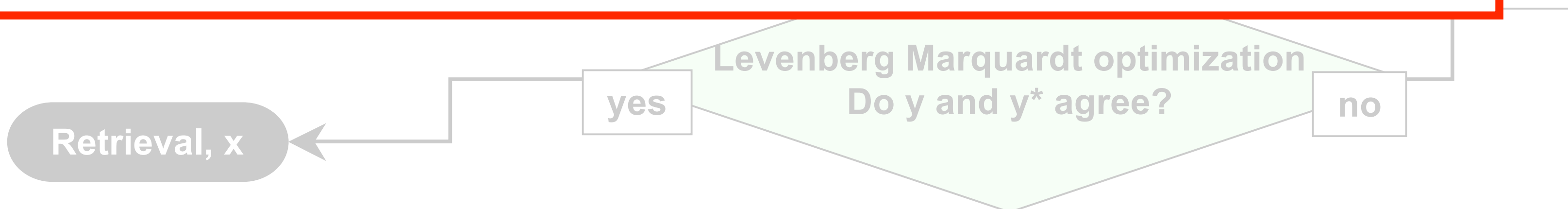
Inversion

Radiative transfer model

Thesis:

Creation of “Doubling and Adding Optimization” (DAO) algorithm and software

DAO used to test RSP/APS capability with data from several field campaigns



see: M. Mishchenko, L. Travis, and D. Mackowski. T-Matrix Computations of Light Scattering by Nonspherical Particles: a Review. *Journal of quantitative spectroscopy & radiative transfer*, 55(5), 1996.

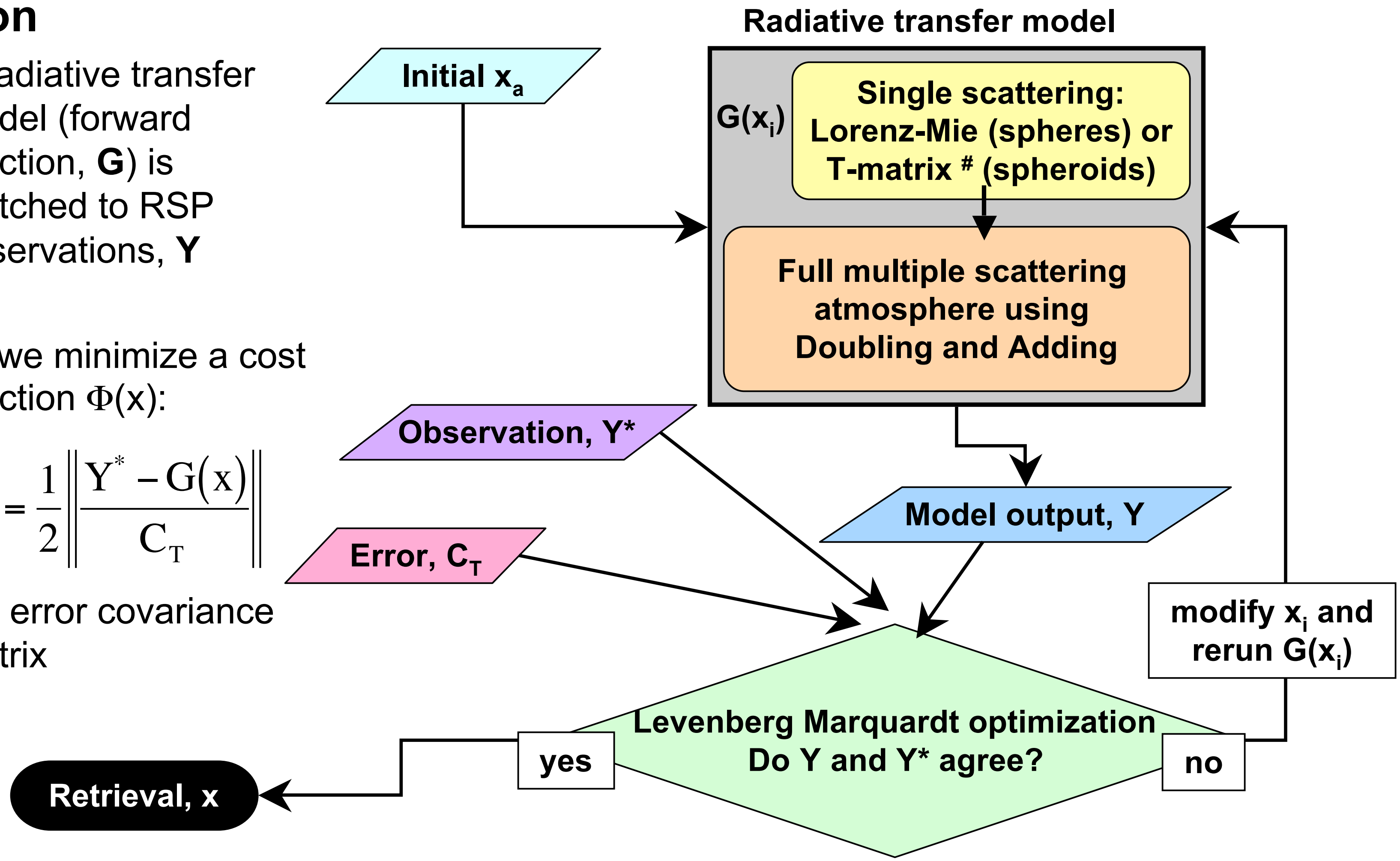
Optimal Estimation

Inversion

- A radiative transfer model (forward function, **G**) is matched to RSP observations, **Y**
- ie. we minimize a cost function $\Phi(x)$:

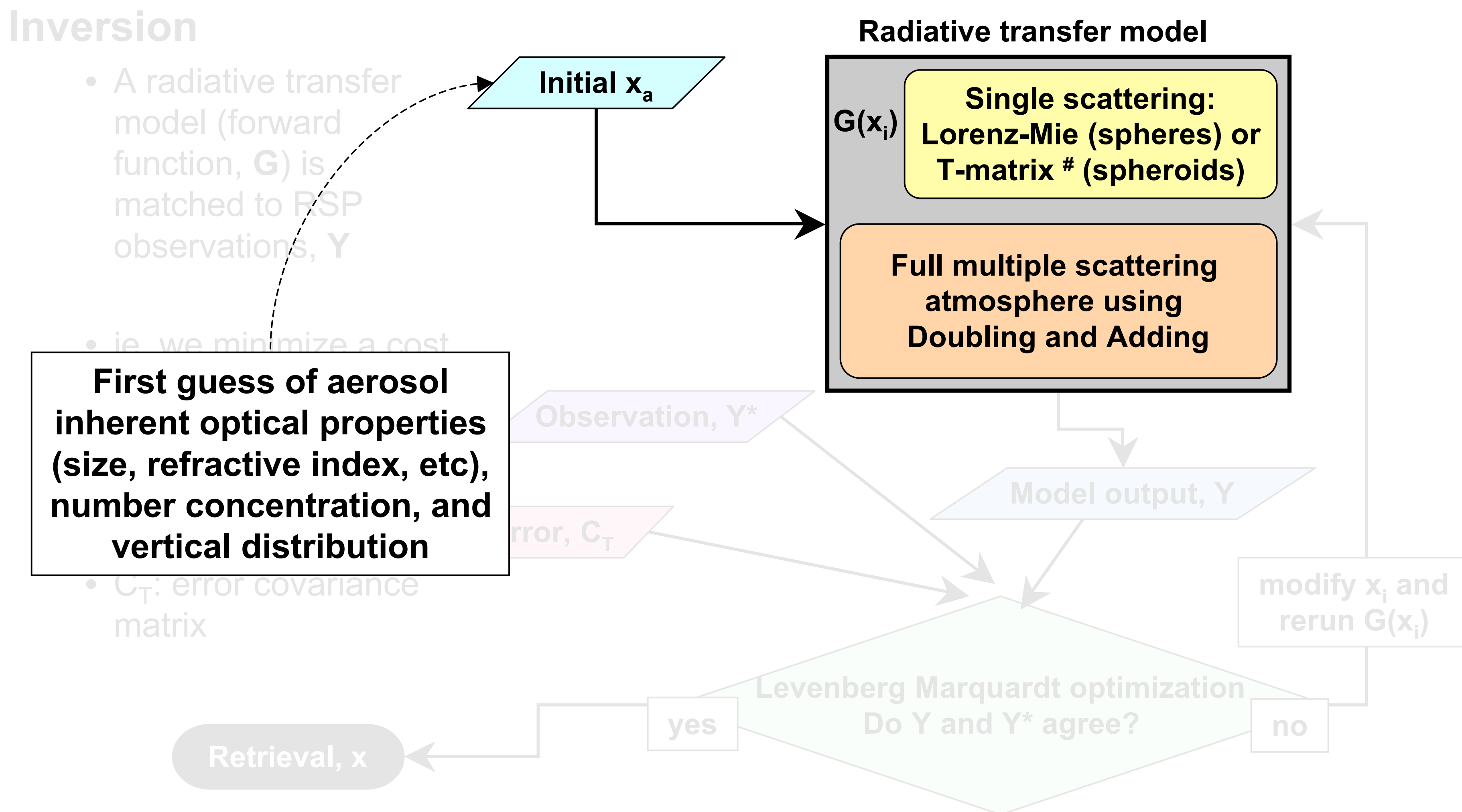
$$\Phi(x) = \frac{1}{2}\left\| \frac{Y^* - G(x)}{C_T} \right\|$$

- C_T: error covariance matrix



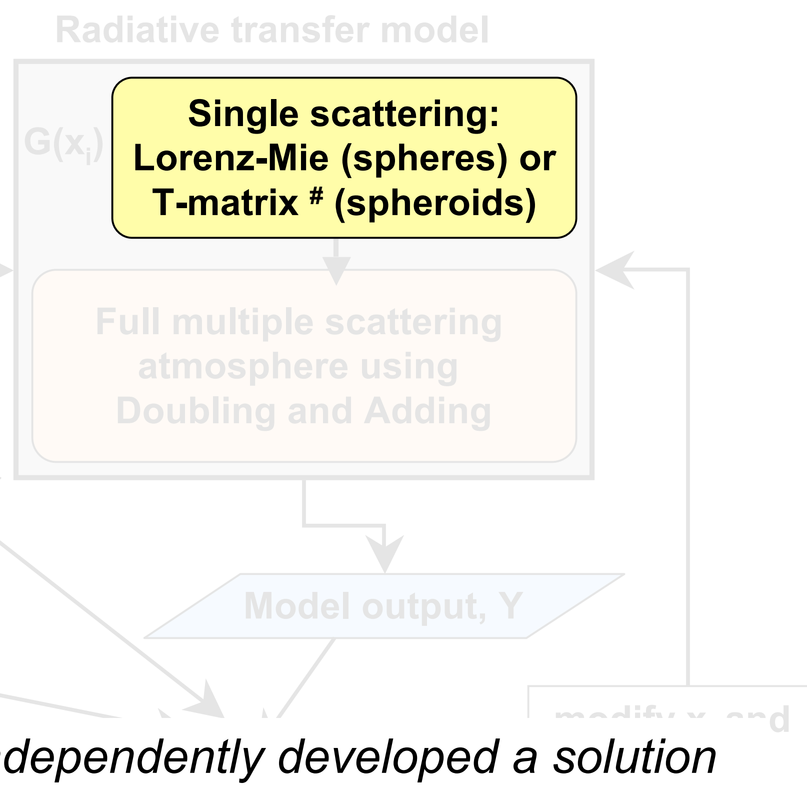
see: M. Mishchenko, L. Travis, and D. Mackowski. T-Matrix Computations of Light Scattering by Nonspherical Particles: a Review. *Journal of quantitative spectroscopy & radiative transfer*, 55(5), 1996.

Optimal Estimation



Single Scattering

Inversion



Lorenz-Mie theory for spheres:

- **Unit Extinction**
- **Unit Absorption**
- **Scattering as a function of angle**

given particle

- **Size distribution**
- **Complex refractive index**

Ludvig Lorenz (1890) and Gustav Mie (1908) independently developed a solution to Maxwell's equations in spherical polar coordinates.

See: M. Mishchenko and L. Travis. Gustav Mie and the evolving discipline of electromagnetic scattering by particles. Bull. Amer. Meteor. Soc., 89(12):1853–1861, 2008.

M. Mishchenko and L. Travis. Capabilities and limitations of a current FORTRAN implementation of the T-matrix method for randomly oriented, rotationally symmetric scatterers-Computational Methods. *J. Quant. Spectrosc. Radiat. Transfer*, 60(3):309–324, 1998.

Optimal Estimation

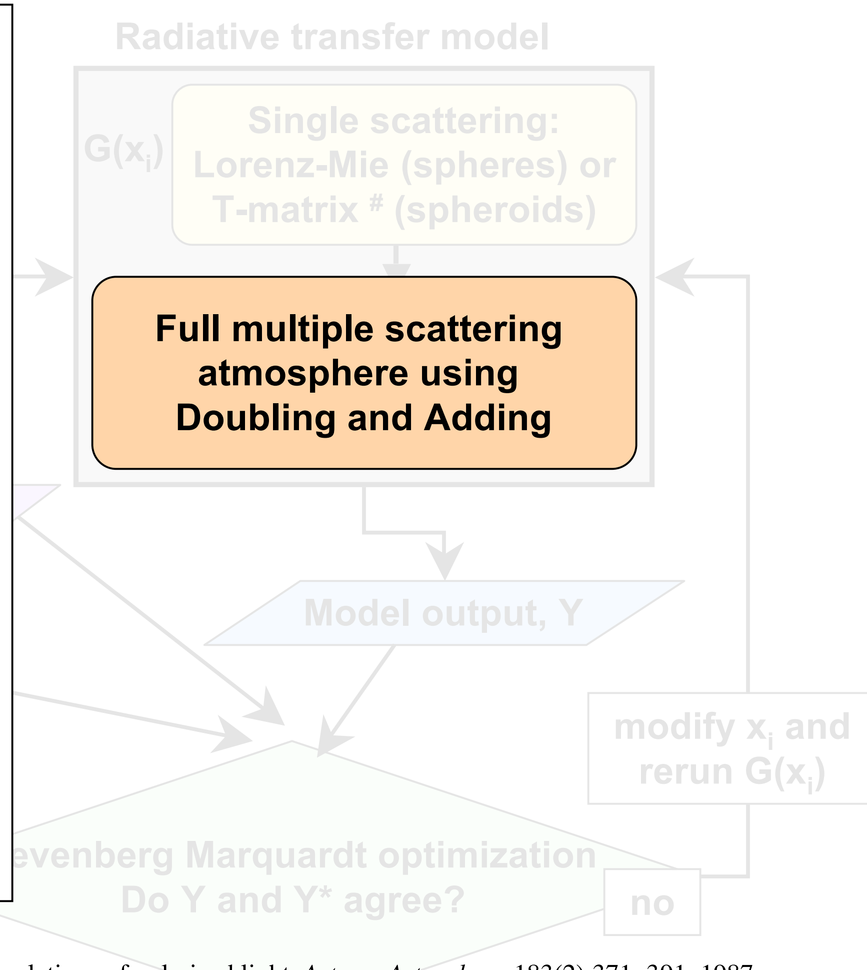
Doubling and Adding technique calculates

- **Multiple scattering**
- **Reflectances at observational geometry**

given

- **Single Scattering from Lorenz-Mie**
- **Aerosol quantity and vertical distribution**
- **Surface reflectance**

(see references below)



J. de Haan, P. Bosma, and J. Hovenier. The adding method for multiple scattering calculations of polarized light. *Astron. Astrophys.*, 183(2):371–391, 1987.
J. Hansen and L. Travis. Light scattering in planetary atmospheres. *Space Science Reviews*, 16:527–610., 1974.
J. Hovenier. Multiple Scattering of Polarized Light in Planetary Atmospheres. *Astron. Astrophys.*, 13:7, 1971.

Optimal Estimation

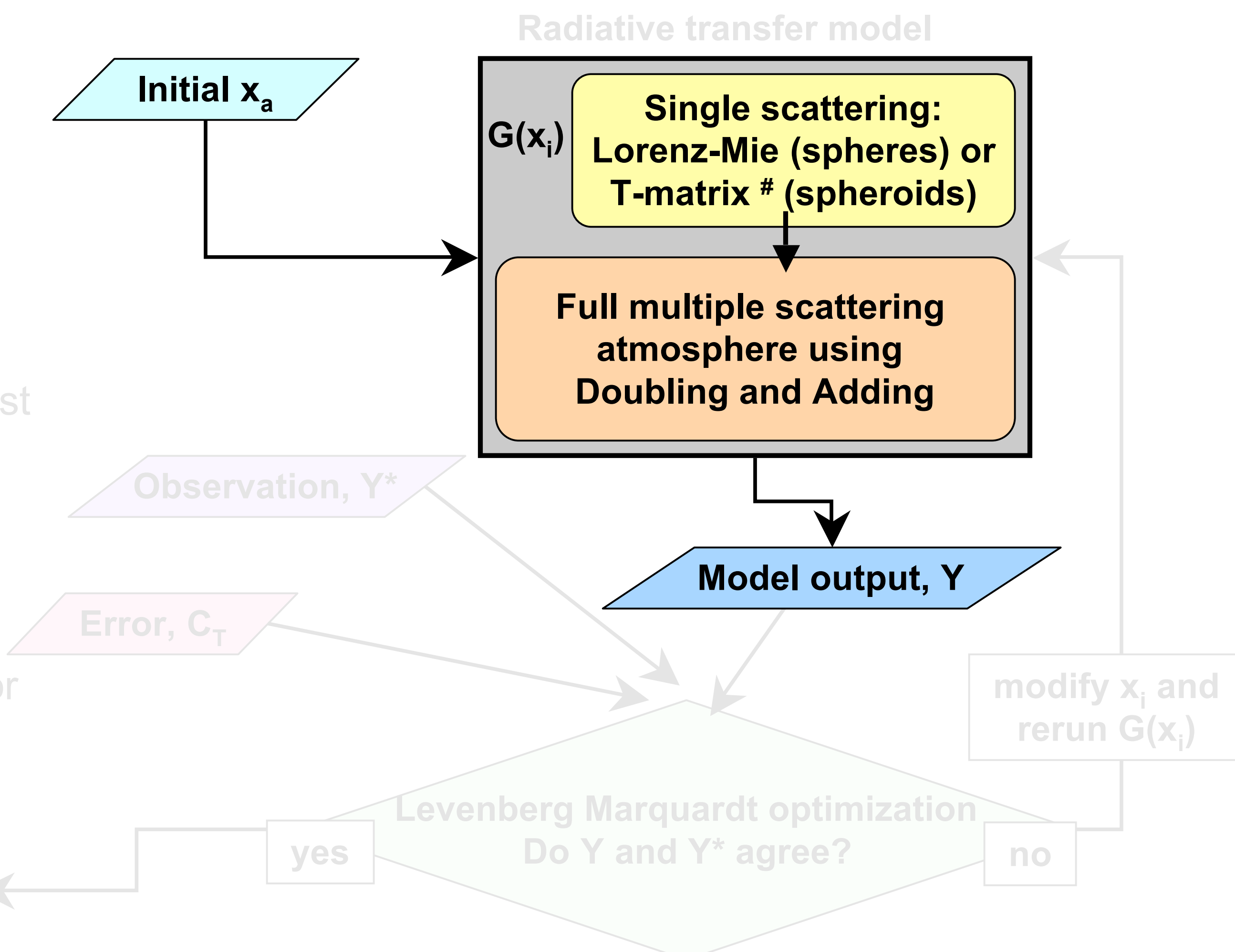
Inversion

- A radiative transfer model (forward function, **G**) is matched to RSP observations, **Y**

- ie. we minimize a cost function $\Phi(x)$:

$$\Phi(x) = \frac{1}{2}\left\| \frac{Y^{*} - G(x)}{C_T} \right\|$$

- C_T: Observation error



Optimal Estimation

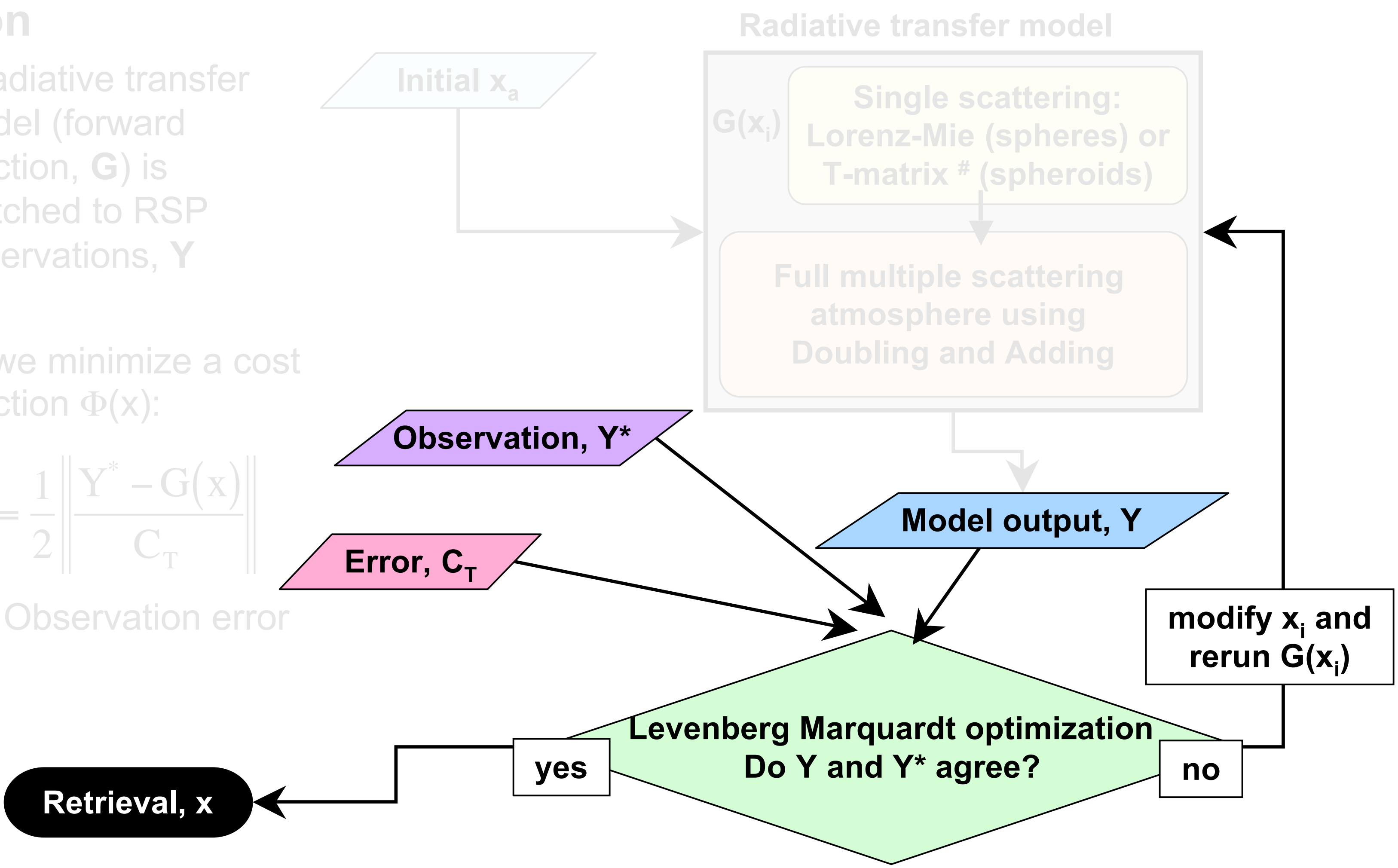
Inversion

- A radiative transfer model (forward function, **G**) is matched to RSP observations, **Y**

- ie. we minimize a cost function $\Phi(x)$:

$$\Phi(x) = \frac{1}{2}\left\| \frac{Y^{*} - G(x)}{C_T} \right\|$$

- C_T: Observation error



Optimal Estimation

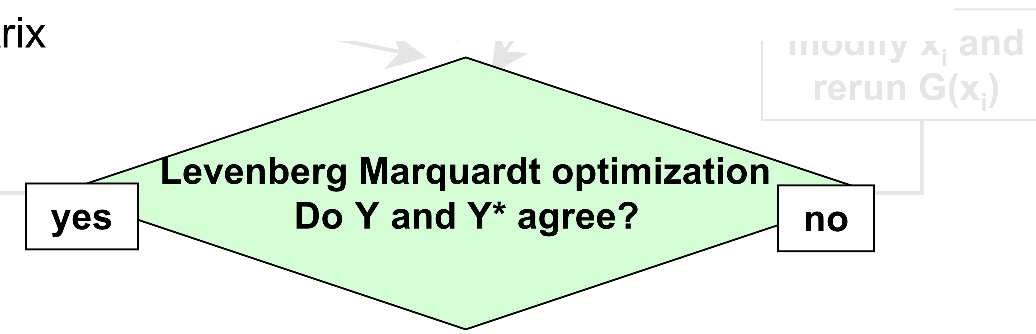
Levenberg-Marquardt optimal estimation

- Iterative search of state space (**x**) to find best match between observations, **Y***, and forward model output: **Y**=G(**x**)
- Intended for nonlinear G(**x**)
- At each iteration step (k), we must numerically estimate the Jacobian matrix:

$$J_k = \left.\frac{\partial G(\mathbf{x})}{\partial \mathbf{x}}\right|_{x = x_k}$$

- Provides accurate error estimates for retrieved parameters, given that observation error covariance matrix is correct

$$C_x = (J^T C_T J)^{-1}$$



Optimal Estimation

DAO Summary

- Doubling and Adding Optimization (DAO) software computes aerosol properties given RSP observations

- This is NOT the software that will be used for Glory APS operational retrievals. BUT it is useful to assess RSP/APS capability, since what is defined as the observation and state vectors (**Y** and **x**, respectively) are easily modified.

- DAO has been used for two chapters in this thesis, both of which will be submitted soon the Atmospheric Chemistry and Physics
  - **ARCTAS** - *Combined retrievals of boreal forest fire aerosol properties with a Polarimeter and a Lidar*
  - **MILAGRO** - *Simultaneous retrieval of aerosol and cloud properties during the MILAGRO field campaign*

1st Case Study a dense smoke plume

Smoke plume observations from the *Arctic Research of the Composition of the Troposphere from Aircraft and Satellites* (**ARCTAS**) field campaign

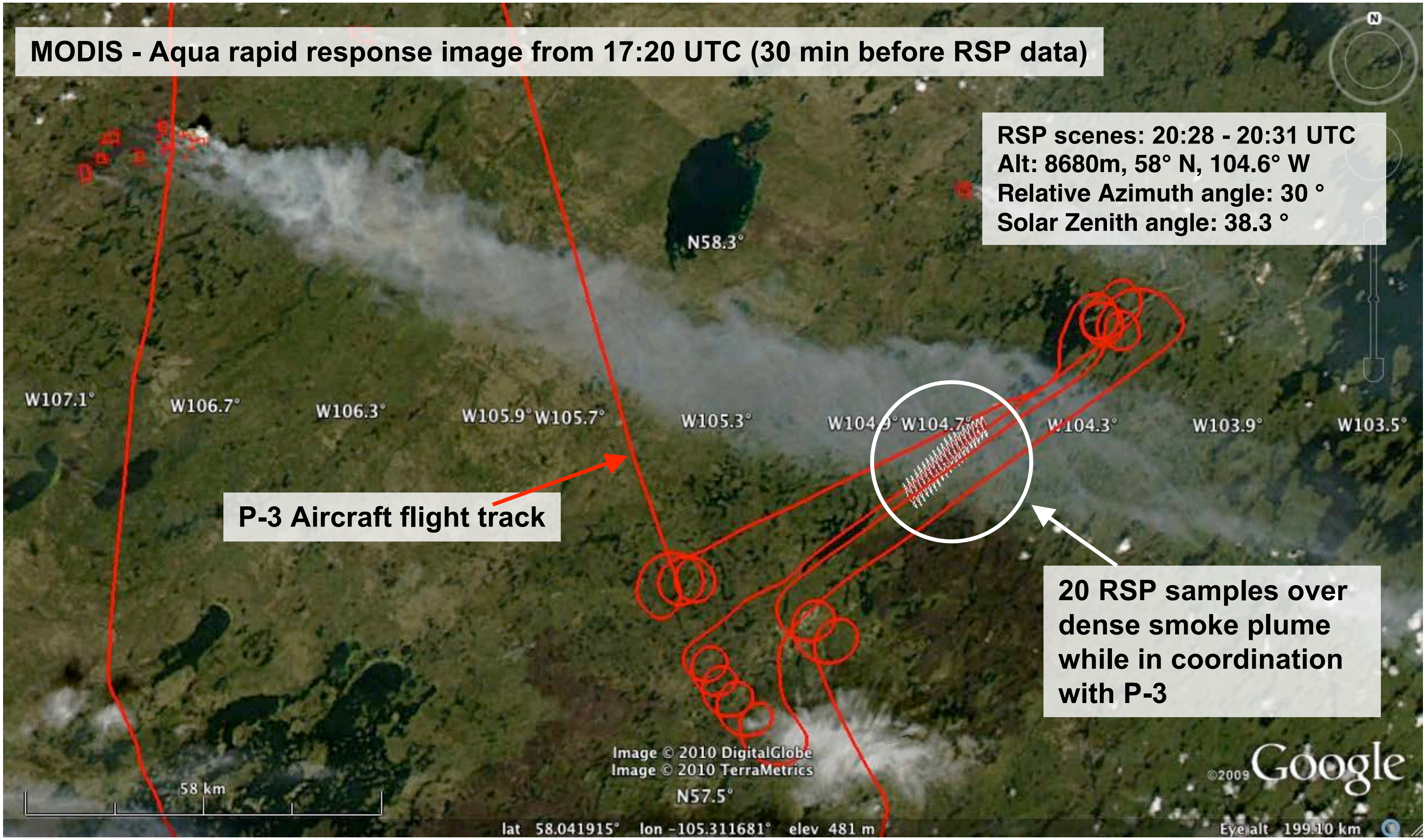
Absorbing aerosols are **difficult** to retrieve **without height** information

Combined polarimeter + LIDAR retrievals may be needed for global estimates of aerosol absorption

ARCTAS

- RSP on the NASA **B200** aircraft, also the High Spectral Resolution Lidar (**HSRL**)
- Summer stage: B200 based in Yellowknife, NWT, Canada June-July 2008
- Flew coordinated flights with **P3** aircraft (*in situ* sampling instrumentation)
- Main goal: observation of **smoke** from **boreal forest fires**

ARCTAS dense smoke scene



ARCTAS dense smoke scene

Data

- 6 RSP polarized channels (410nm, 470nm, 555nm, 670nm, 865nm, and 1590nm)
- 1 RSP total reflectance channel (410nm)
- ~75 Angular observations between 20° forward (toward the sun) and 40° backwards
- Total number of observations: 525

Assumptions

- **Aerosol**: are so optically thick that the ground reflectance is unimportant for the shortest wavelength (**this allows the use of of total reflectance at 410nm**)
- Complex refractive index is spectrally constant
- Aerosols are spheres

Test

- Aerosol retrieval **without height information** (distributed between ground and retrieved top altitude), **vs**
- Aerosol retrieval **using aerosol layer heights from HSRL**

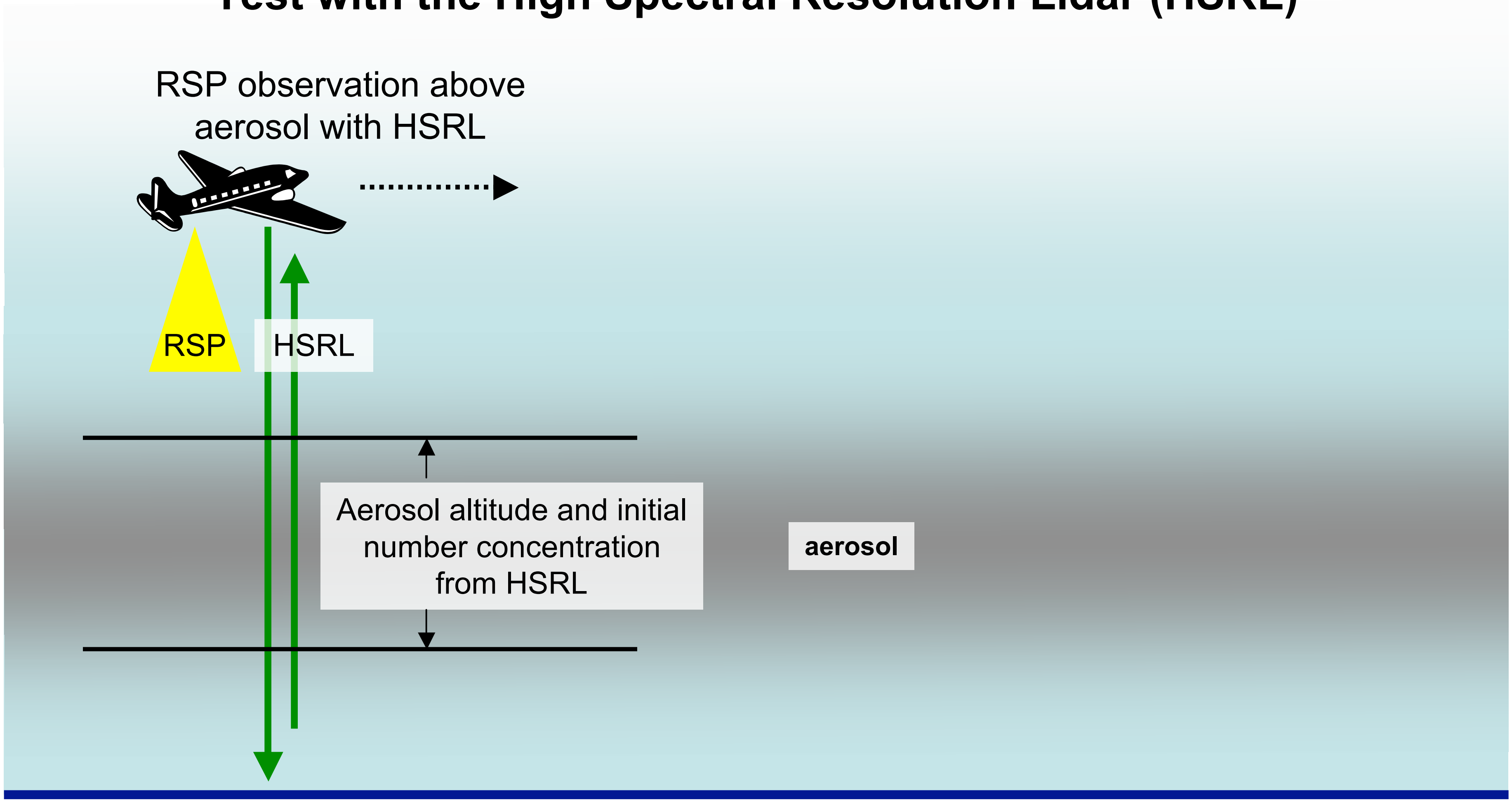
Initial values

- Boreal forest fire AERONET model from Dubovik et al. 2002

ARCTAS dense smoke scene

Are combined polarimeter-lidar retrievals better?

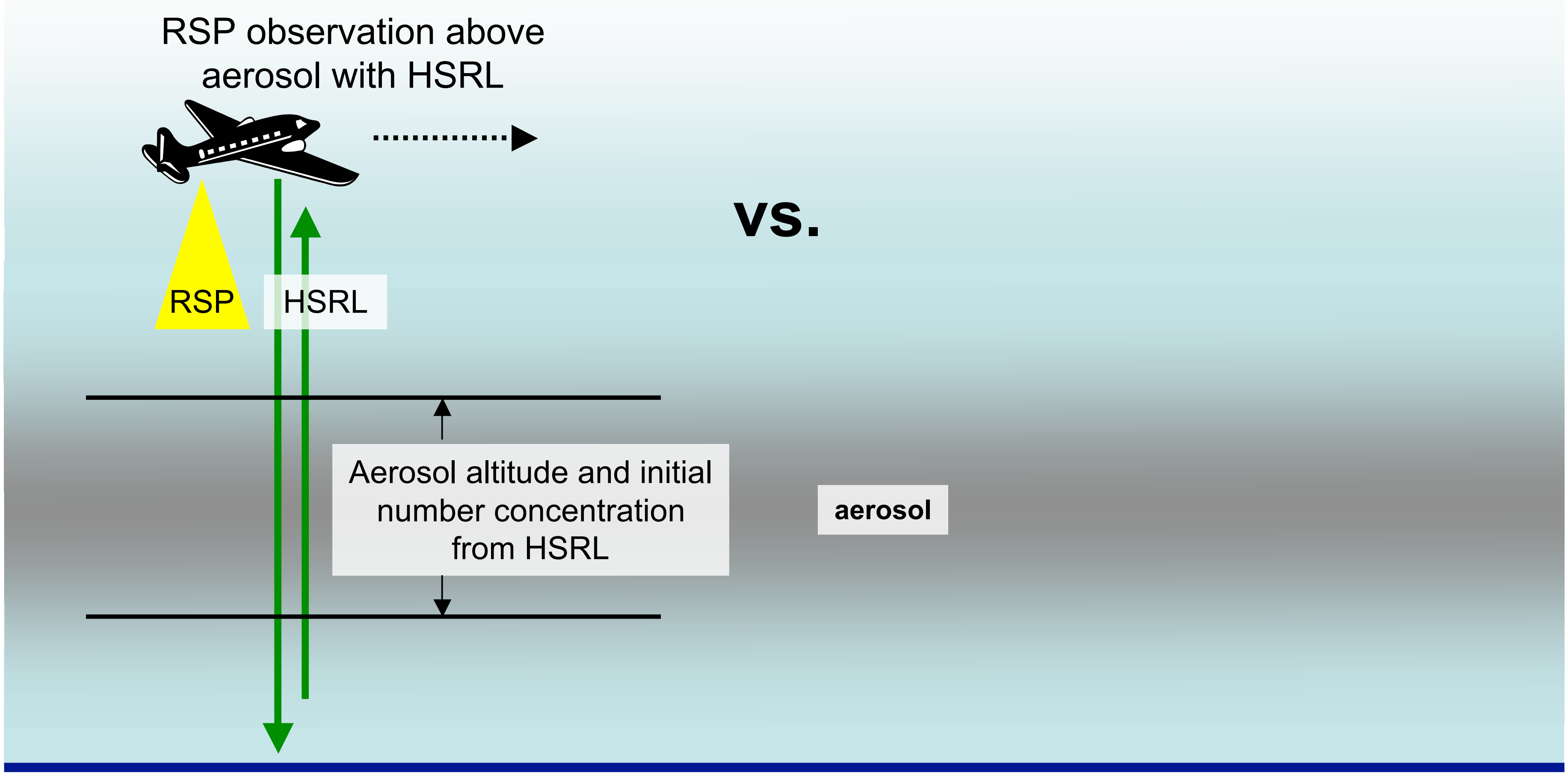
Test with the High Spectral Resolution Lidar (HSRL)



ARCTAS dense smoke scene

Are combined polarimeter-lidar retrievals better?

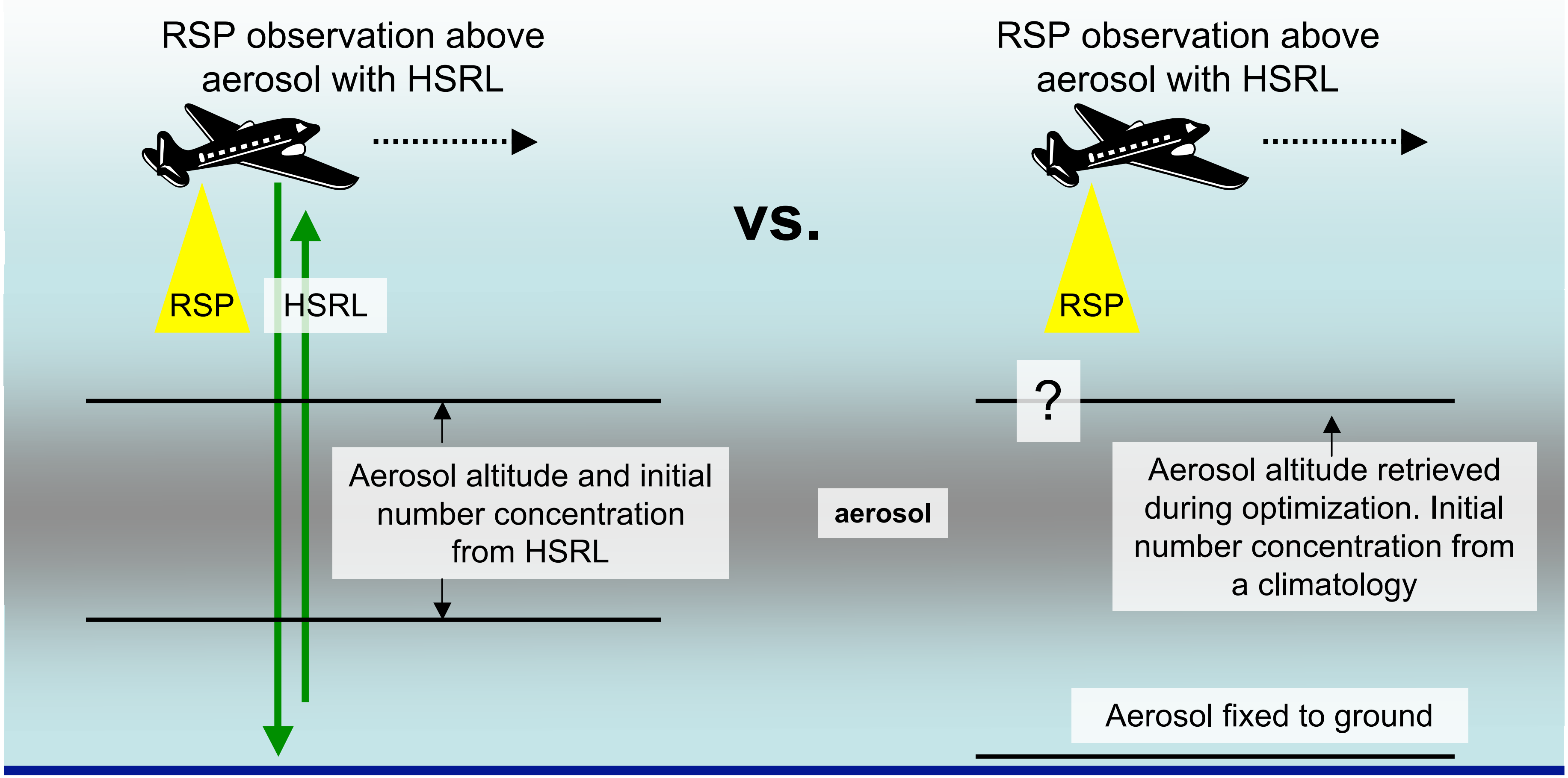
Test with the High Spectral Resolution Lidar (HSRL)



ARCTAS dense smoke scene

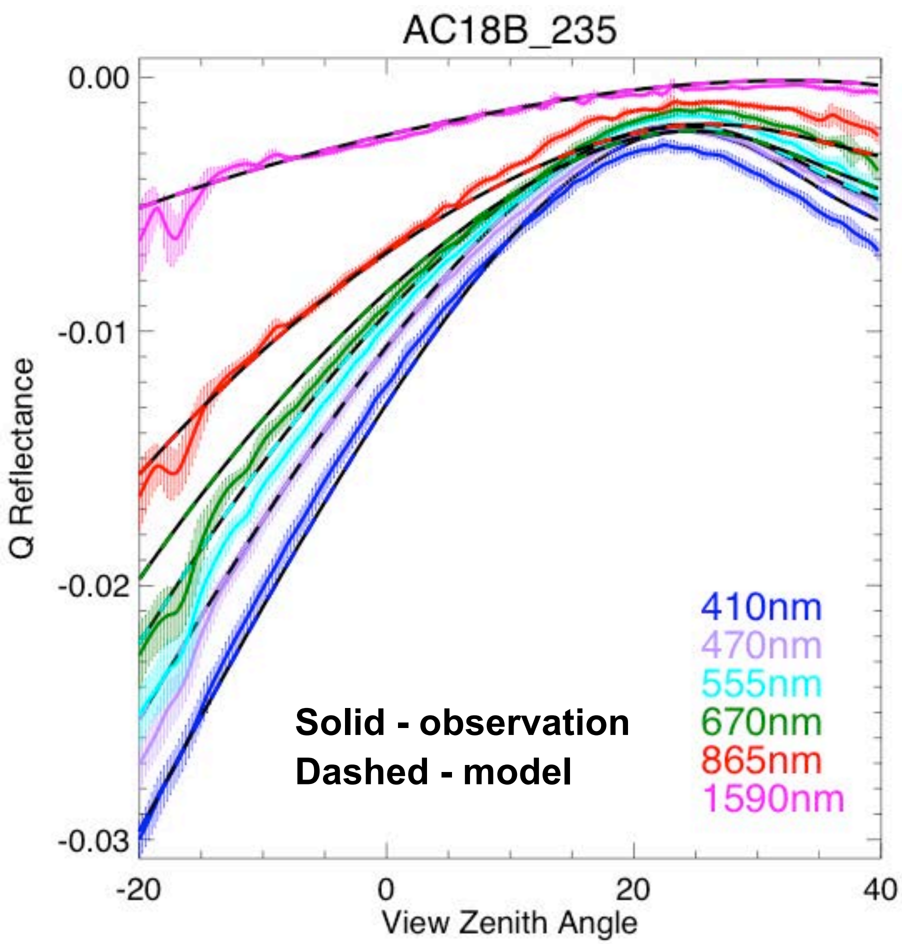
Are combined polarimeter-lidar retrievals better?

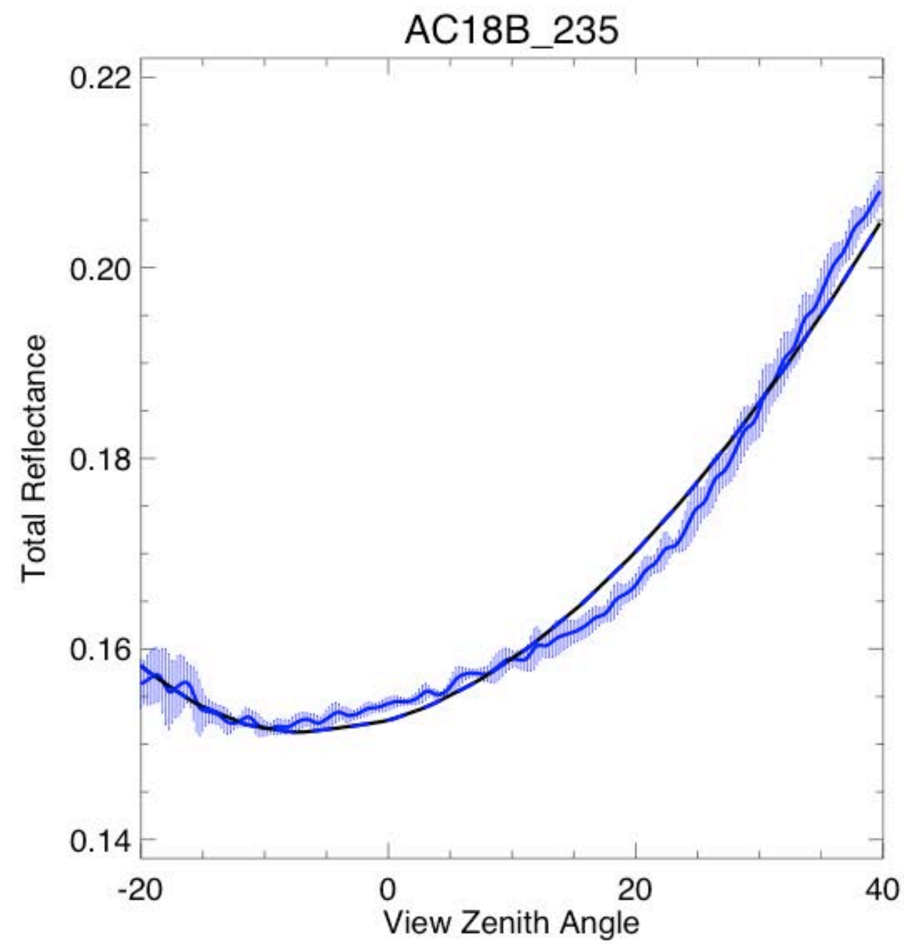
Test with the High Spectral Resolution Lidar (HSRL)



ARCTAS dense smoke scene

Example retrieval from one of 20 scenes





410nm 470nm 555nm 670nm 865nm 1590nm

ARCTAS dense smoke scene

	With HSRL		Without HSRL	
Fine mode Aerosol				
Real Refractive Index	**1.45**	**± 0.05**	**1.55**	**± 0.08**
Imaginary Refractive Index	**0.005**	**± 0.0036**	**0.016**	**± 0.0064**
Effective Radius [μm]	**0.14**	**± 0.02**	**0.11**	**± 0.01**
Effective Variance	**0.24**	**± 0.05**	**0.32**	**± 0.05**
Number Concentration	**17.0**	**± 0.11**	**61.7**	**± 0.18**
Coarse mode Aerosol				
Number Concentration	**0.0009**	**± 0.001**	**0.0001**	**± 0.002**
Derived parameters				
Aerosol Optical Thickness, 532nm	**0.70**	**± 0.39**	**0.67**	**± 0.30**
Single Scattering Albedo*, 532nm	**0.96**	**± 0.02**	**0.92**	**± 0.03**

* (fine mode)

Values are the **mean** for the set

ARCTAS dense smoke scene

Retrievals are different

	With HSRL		Without HSRL	
Fine mode Aerosol				
Real Refractive Index	**1.45**	± 0.05	**1.55**	**± 0.08**
Imaginary Refractive Index	**0.005**	± 0.0036	**0.016**	**± 0.0064**
Effective Radius [μm]	**0.14**	± 0.02	**0.11**	**± 0.01**
Effective Variance	**0.24**	± 0.05	**0.32**	**± 0.05**
Number Concentration	**17.0**	± 0.11	**61.7**	**± 0.18**
Coarse mode Aerosol				
Number Concentration	**0.0009**	**± 0.001**	**0.0001**	**± 0.002**
Derived parameters				
Aerosol Optical Thickness, 532nm	**0.70**	**± 0.39**	**0.67**	**± 0.30**
Single Scattering Albedo*, 532nm	**0.96**	**± 0.02**	**0.92**	**± 0.03**

* (fine mode)

Values are the **mean** for the set

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

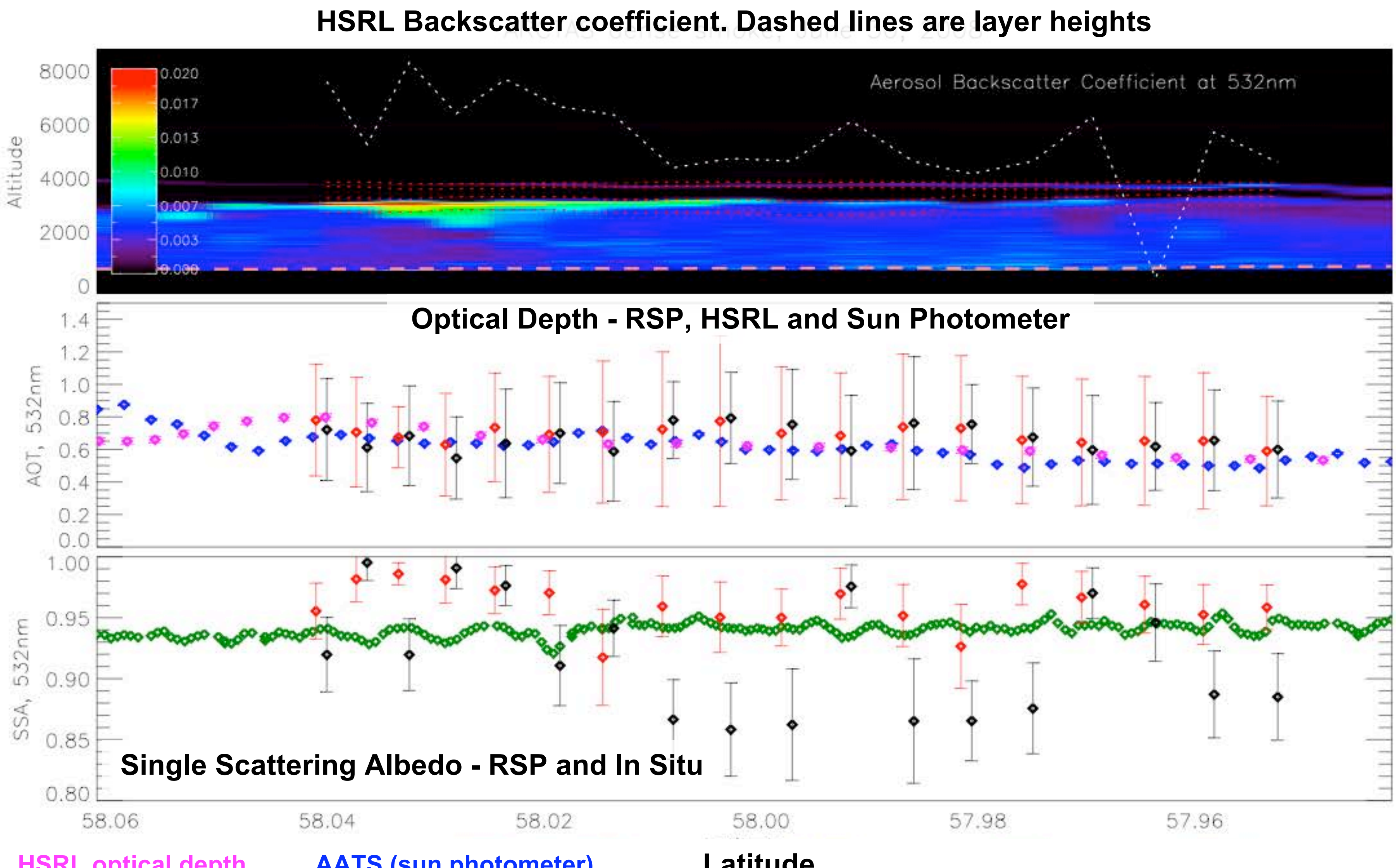
ARCTAS dense smoke scene

Retrievals are different

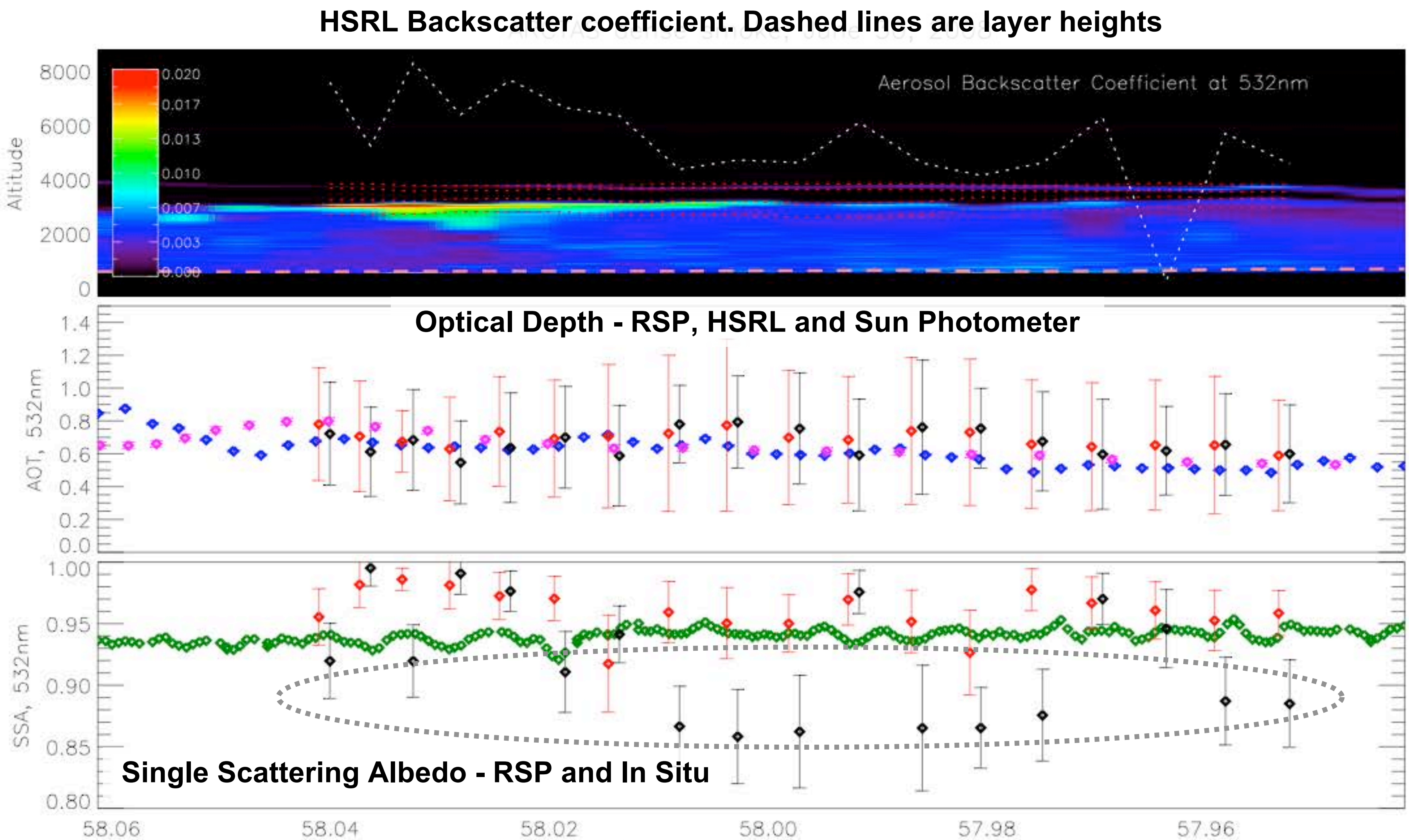
	With HSRL		Without HSRL	
Fine mode Aerosol				
Real Refractive Index	**1.45**	**± 0.05**	**1.55**	**± 0.08**
Imaginary Refractive Index	**0.005**	**± 0.0036**	**0.016**	**± 0.0064**
Effective Radius [µm]	**0.14**	**± 0.02**	**0.11**	**± 0.01**
Effective Variance	**0.24**	**± 0.05**	**0.32**	**± 0.05**
Number Concentration	**17.0**	**± 0.11**	**61.7**	**± 0.18**
Coarse mode Aerosol				
Number Concentration	**0.0009**	**± 0.001**	**0.0001**	**± 0.002**
Derived parameters				
Aerosol Optical Thickness, 532nm	**0.70**	**± 0.39**	**0.67**	**± 0.30**
Single Scattering Albedo*, 532nm	**0.96**	**± 0.02**	**0.92**	**± 0.03**

* (fine mode)

But optical depth is similar…



HSRL optical depth
HiGEAR (in situ)
RSP - layers attached to ground
AATS (sun photometer)
RSP - HSRL specified layers



HSRL optical depth
HiGEAR (in situ)
RSP - layers attached to ground

AATS (sun photometer)
RSP - HSRL specified layers

Latitude

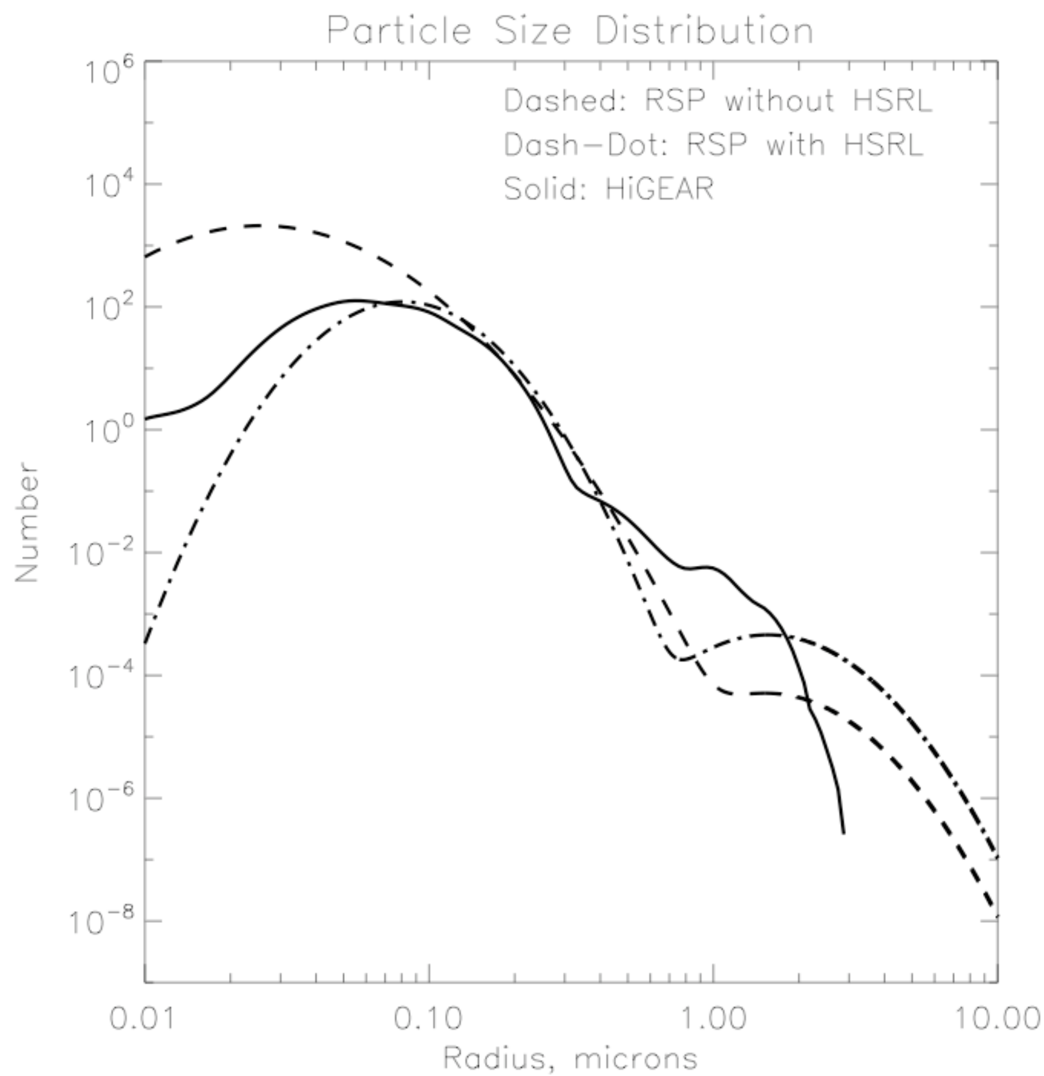
February 23, 2011

ARCTAS dense smoke scene

We are encountering two different minima, which are equally valid in parameter space

Both scenarios produce a size distribution that is **strikingly similar to in situ observations** and each other in the 0.1-0.4 μm radius range

Geophysically “correct” results are **certain only if optimization is started close to solution**

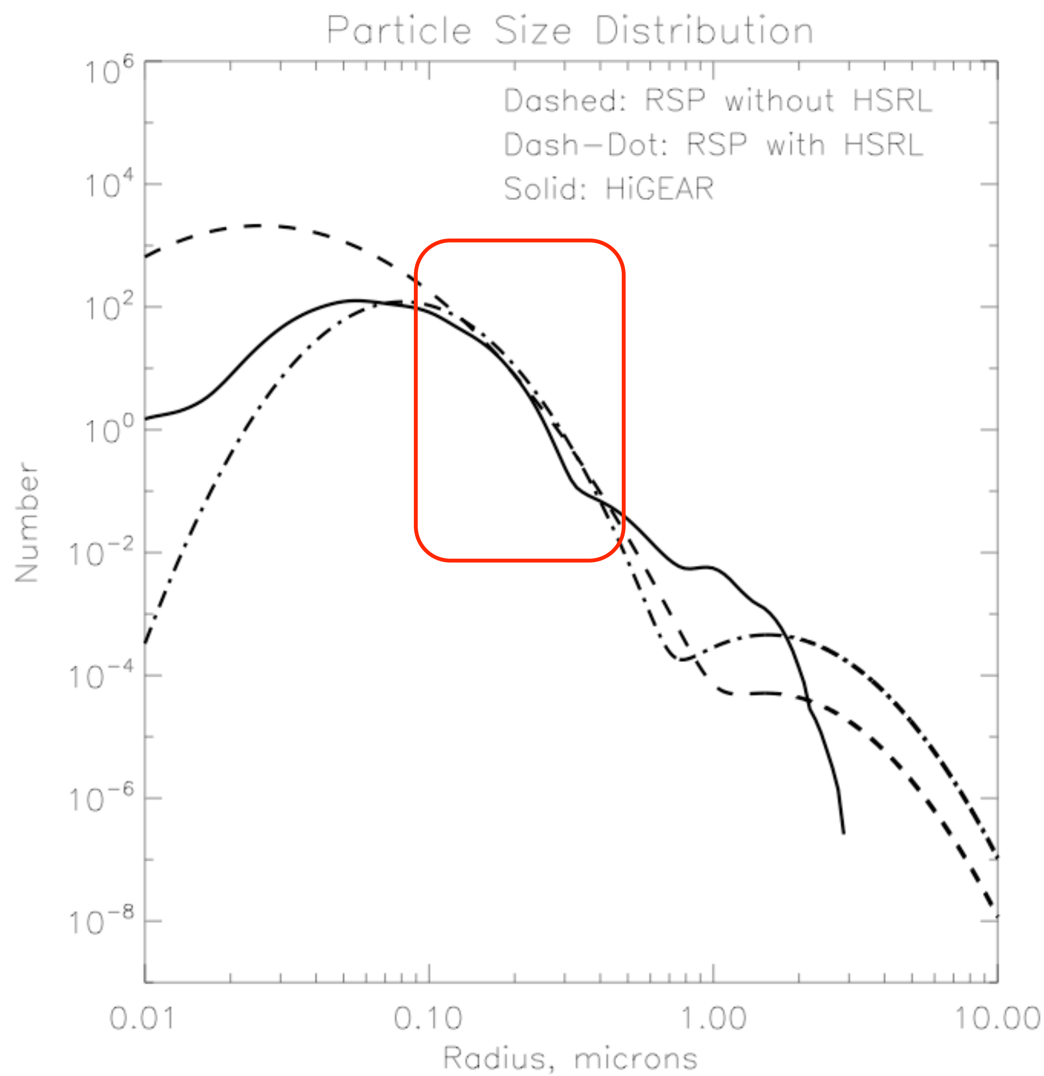


ARCTAS dense smoke scene

We are encountering two different minima, which are equally valid in parameter space

Both scenarios produce a size distribution that is **strikingly similar to in situ observations** and each other in the 0.1-0.4 μm radius range

Geophysically "correct" results are **certain only if optimization is started close to solution**



ARCTAS dense smoke scene

Interpretation and Conclusions

- About half of the retrievals without HSRL data converge to a false minima
- The false minima is expressed in fine mode size and refractive index, but not optical depth
- “Successful” retrievals without HSRL data are similar to those that use HSRL aerosol layer heights
- **Accurate initial number concentration estimates are important, vertical distribution less so.**

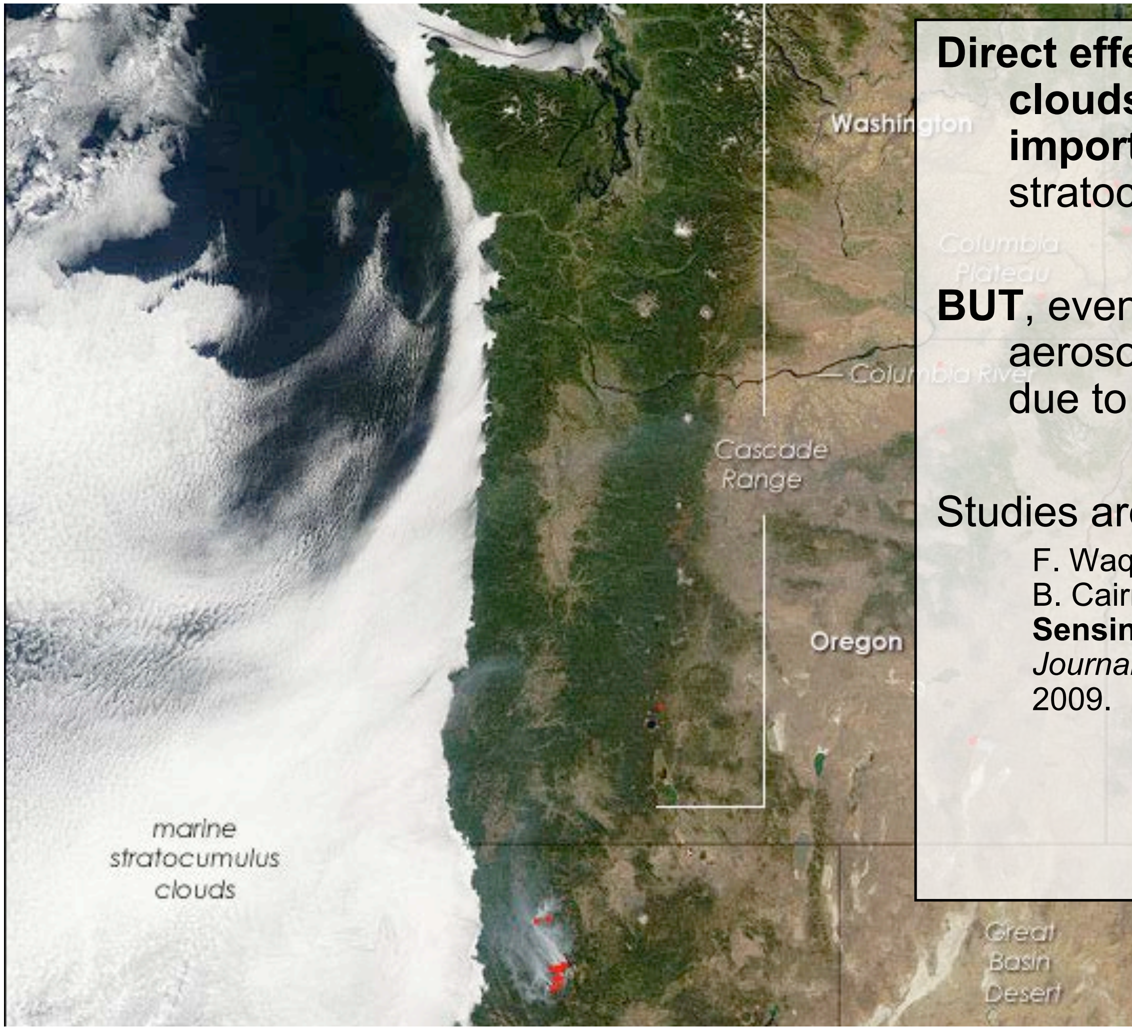
- Large aerosol optical thickness error, despite similarity in results. This is motivation for changes in next chapter.

- We have no *in situ* comparisons for refractive index

- Lidar data could be used in more sophisticated ways - such as vertical profiles

2nd Case Study aerosols over clouds

MODIS Terra image from NASA Earth Observatory



Direct effect of aerosols lofted above clouds could be **climatologically important** - especially for low level marine stratocumulus clouds

BUT, even the sign of the radiative forcing of aerosols in cloudy regions is **unknown#**, due to a **lack of data**

Studies are just beginning

F. Waquet, J. Riedi, L. Labonnote, P. Goloub, B. Cairns, J. Deuzé, and D. Tanré. **Aerosol Remote Sensing over Clouds Using A-Train Observations**. *Journal of the Atmospheric Sciences*, 66(8):2468–2480, 2009.

see: M. Schulz, C. Textor, S. Kinne, Y. Balkanski, S. Bauer, T. Berntsen, T. Berglen, O. Boucher, F. Dentener, S. Guibert, et al. Radiative forcing by aerosols as derived from the AeroCom present-day and pre-industrial simulations. *Atmospheric Chemistry and Physics*, 6(12):5246, 2006.

MILAGRO Aerosol over cloud

We look at a scene from the Megacity Initiative: Local and Global Research Observations **(MILAGRO)** field campaign, based in central Mexico in April and March of 2006

Jetstream-31 aircraft had:

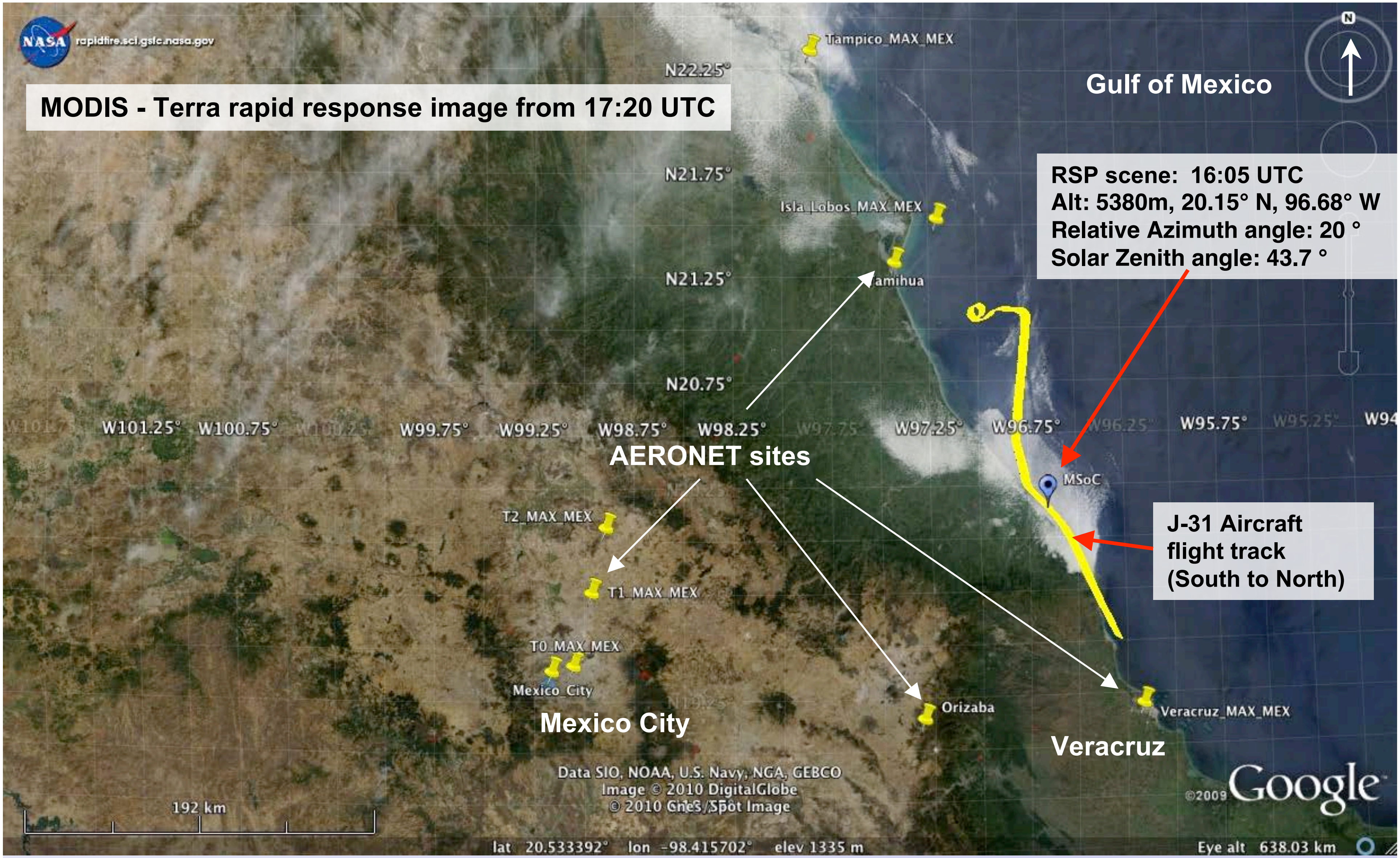
- Solar Spectral Flux Radiometer (**SSFR**)
- Cloud Absorption Radiometer (**CAR**)
- Ames Airborne Tracking Sunphotometer (**AATS-14**)

- Research Scanning Polarimeter (**RSP**)

Nearby AERONET sites with data

- Tamihua - 145 km North West
- T2 MaxMex - 230 km West

MILAGRO Aerosol over cloud



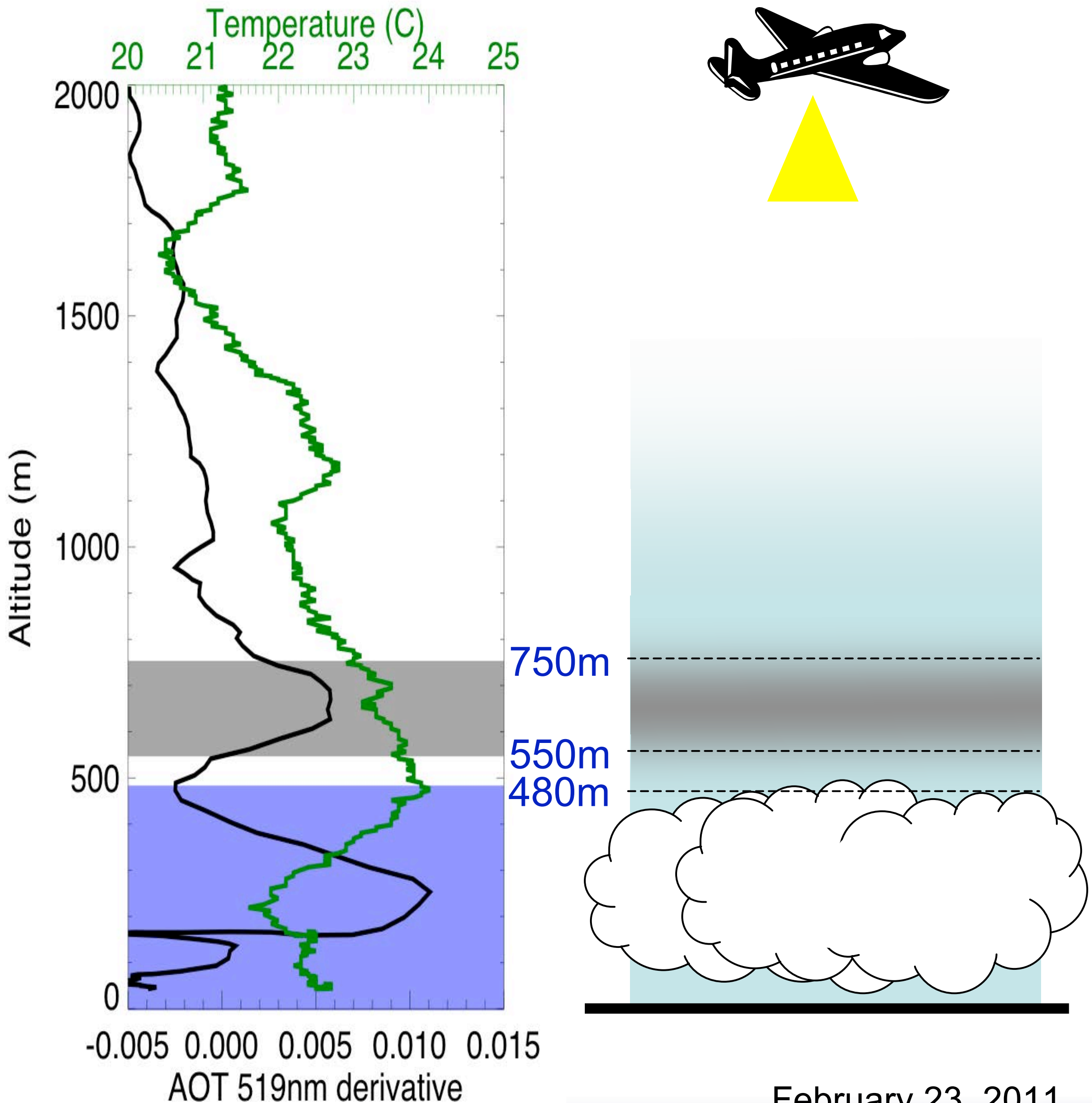
MILAGRO Aerosol over cloud

Scene

- Near shore, dissipating, marine stratocumulus cloud
- Moderate aerosol overlay
- Aerosols are aged, mixed and stagnant, primarily from fires and industrial/urban pollution ir the Mexico City valley

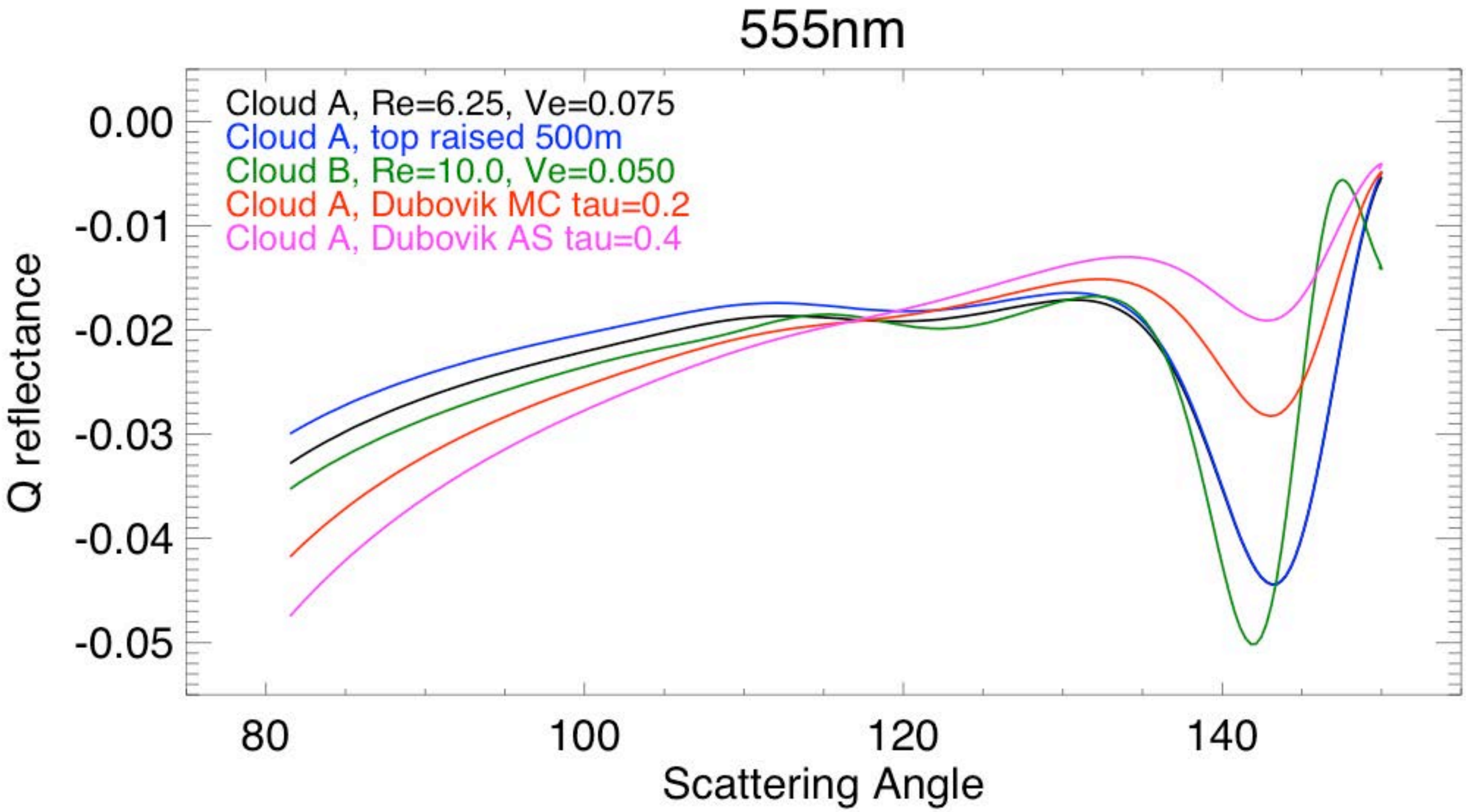
Vertical distribution from external data

- Aerosol height from a sun photometer during an aircraft vertical spiral
- Cloud top height from temperature in the same spiral



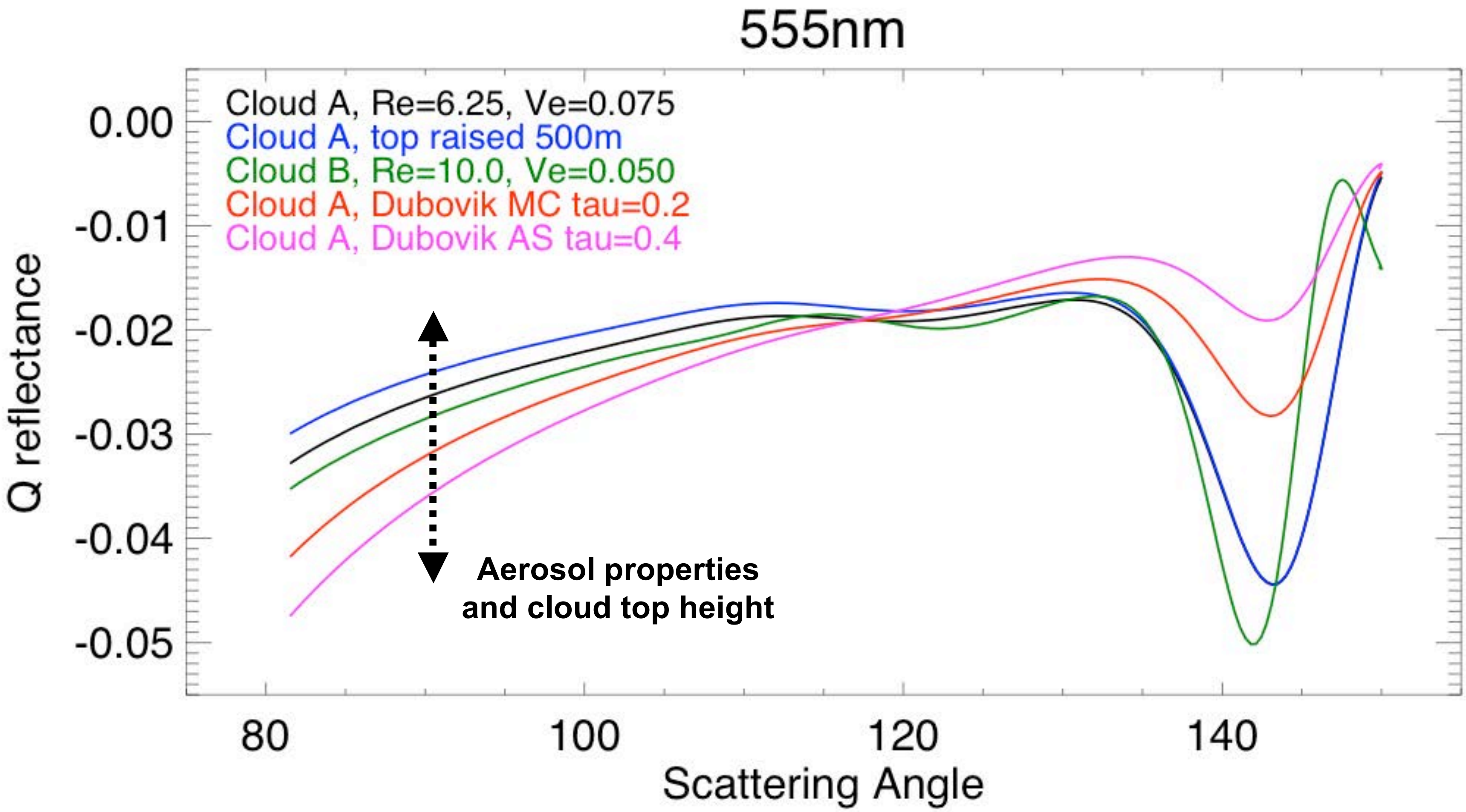
MILAGRO Aerosol over cloud

Polarized observations can distinguish aerosol and cloud optical properties *and are insensitive to cloud optical depth (above ~3)*



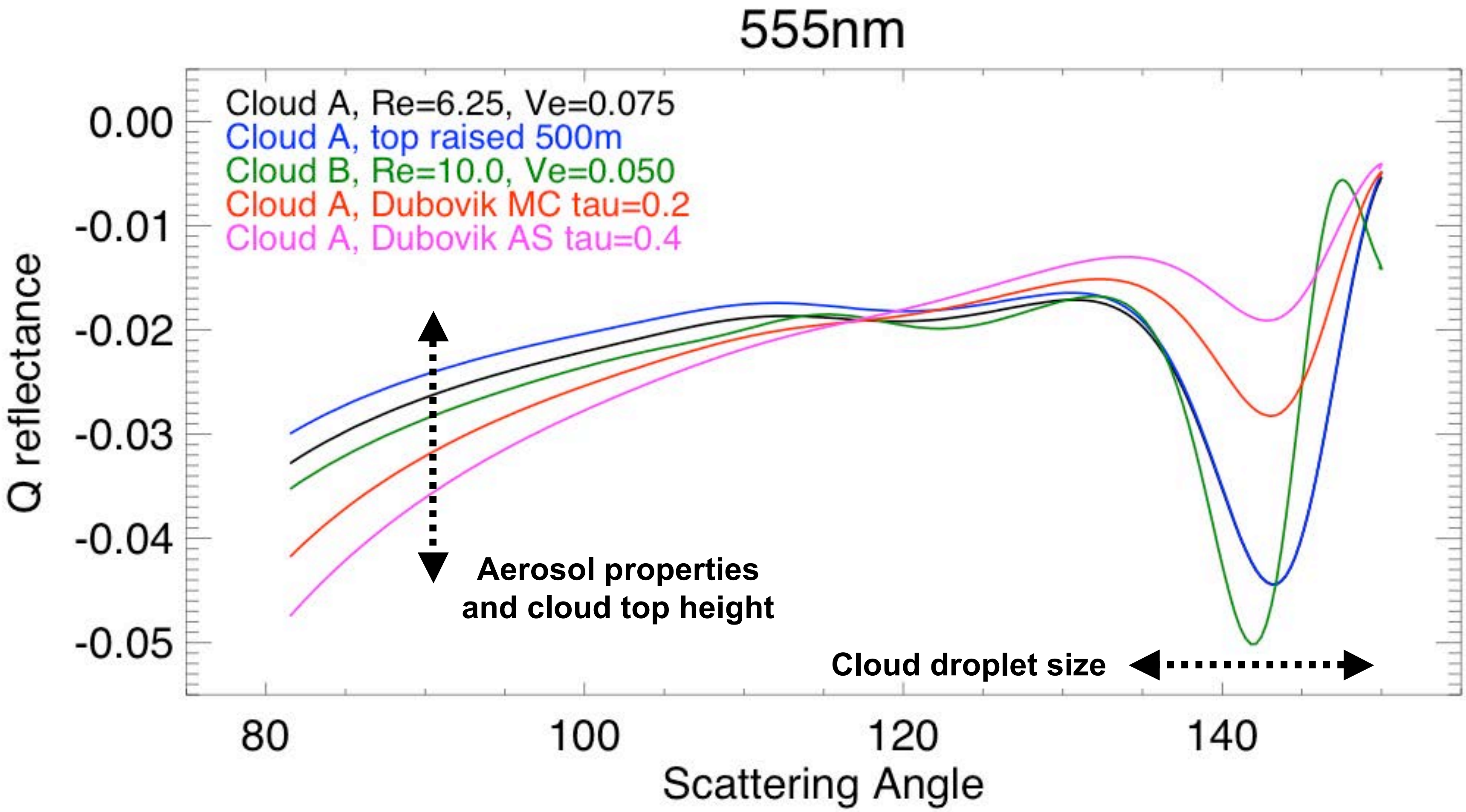
MILAGRO Aerosol over cloud

Polarized observations can distinguish aerosol and cloud optical properties *and are insensitive to cloud optical depth (above ~3)*



MILAGRO Aerosol over cloud

Polarized observations can distinguish aerosol and cloud optical properties *and are insensitive to cloud optical depth (above ~3)*



MILAGRO Aerosol over cloud

Simulations can be used to assess sensitivity using the Jacobian

The Jacobian for a simulation can be used to project observational error to state (parameter) space

$$C_x = (J^T C_T J)^{-1}$$

$$J = \frac{\partial G(\mathbf{x})}{\partial \mathbf{x}}$$

Jacobian

Forward model

Parameters

Simulated parameter error

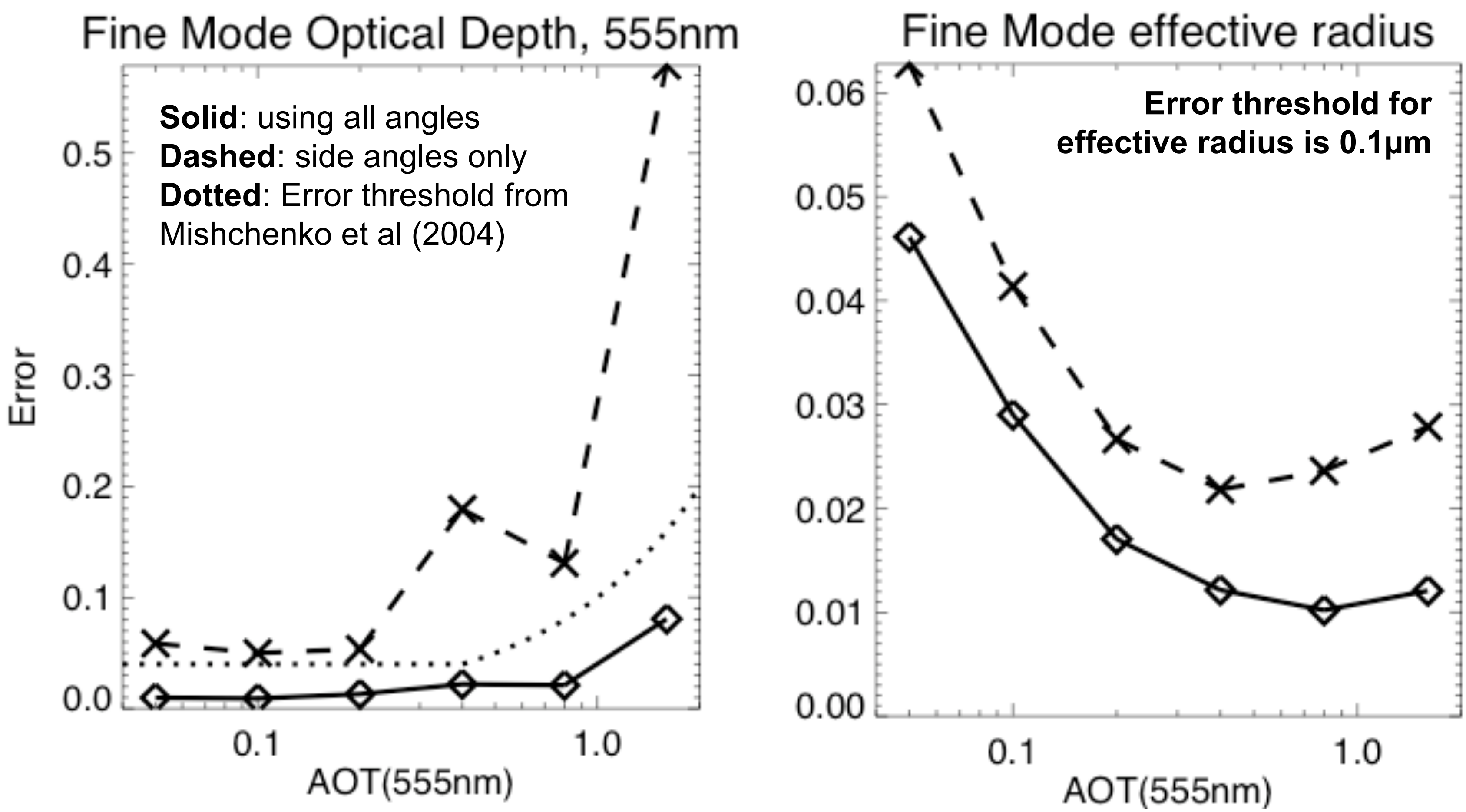
Observation error

This is useful to help us choose the best retrieval strategy

Example: is it better to use observations at all view angles, or only where aerosols have the most influence?

MILAGRO Aerosol over cloud

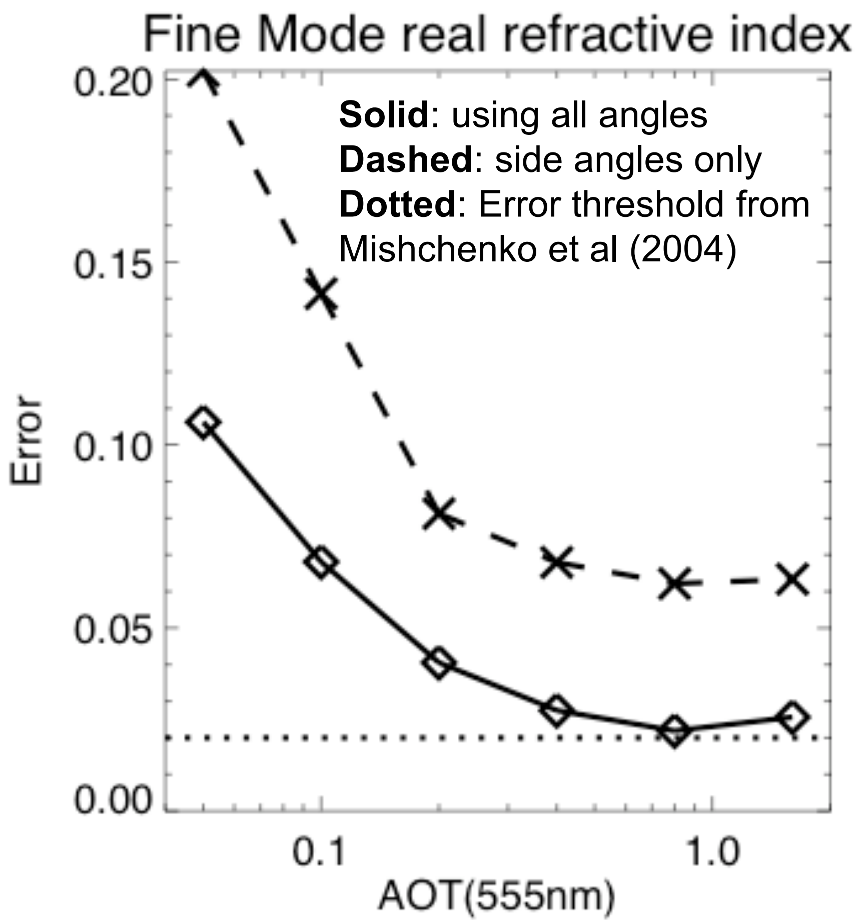
Simulations can be used to assess sensitivity using the Jacobian

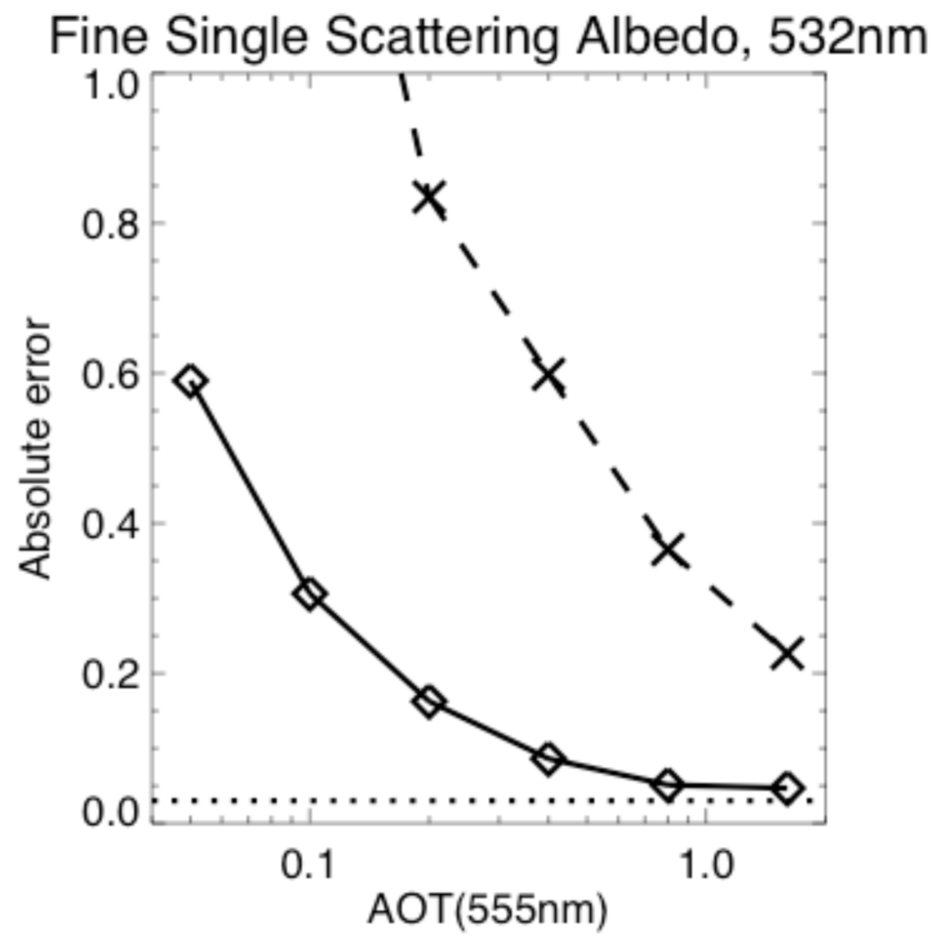


M. Mishchenko, B. Cairns, J. Hansen, L. Travis, R. Burg, Y. Kaufman, J. Vanderlei Martins, and E. Shettle. Monitoring of aerosol forcing of climate from space: analysis of measurement requirements. *J. Quant. Spectrosc. Radiat. Transfer*, 88(1-3):149–161, 2004.

MILAGRO Aerosol over cloud

Simulations can be used to assess sensitivity using the Jacobian

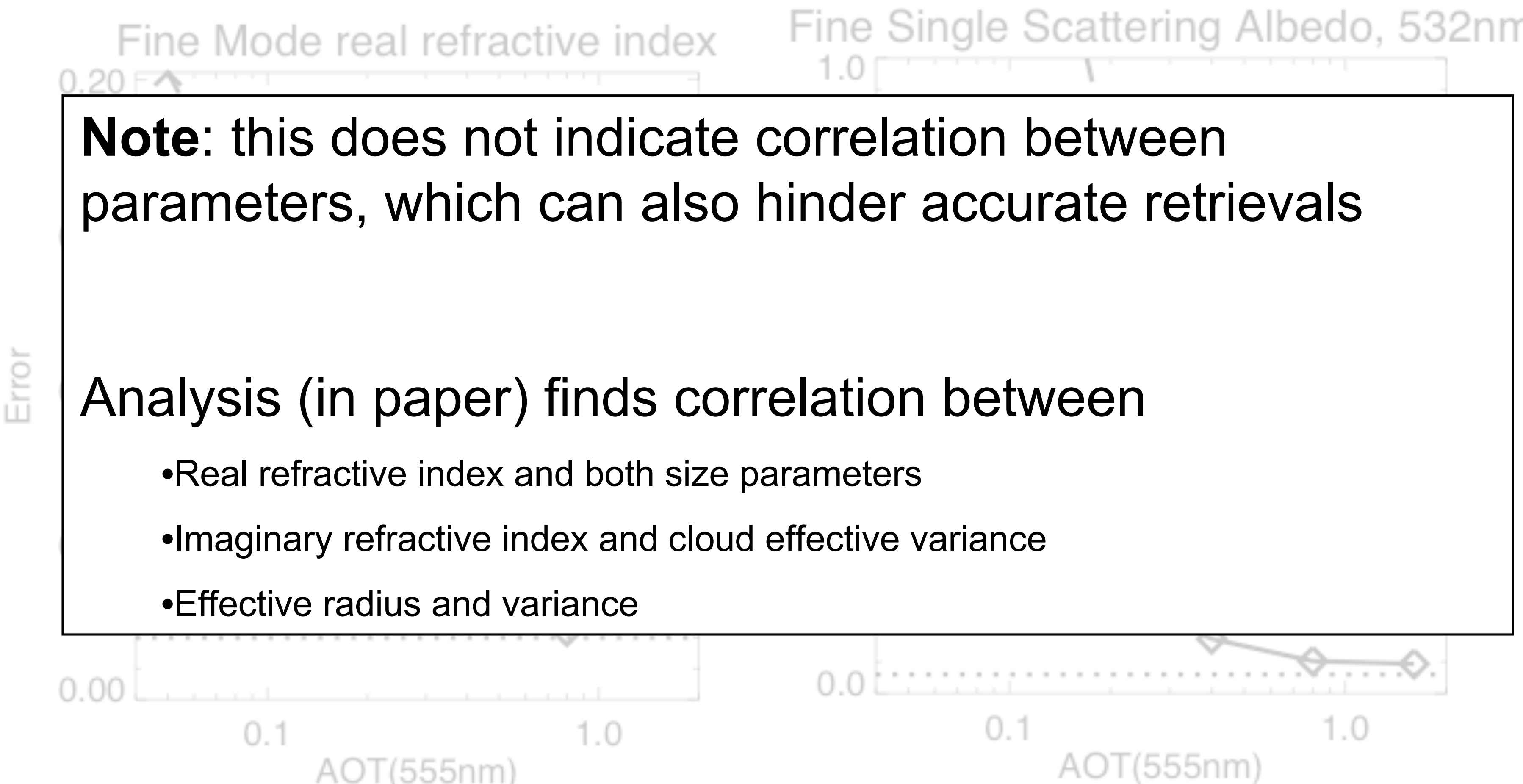




M. Mishchenko, B. Cairns, J. Hansen, L. Travis, R. Burg, Y. Kaufman, J. Vanderlei Martins, and E. Shettle. Monitoring of aerosol forcing of climate from space: analysis of measurement requirements. *J. Quant. Spectrosc. Radiat. Transfer*, 88(1-3):149–161, 2004.

MILAGRO Aerosol over cloud

Simulations can be used to assess sensitivity using the Jacobian



Note: this does not indicate correlation between parameters, which can also hinder accurate retrievals

Analysis (in paper) finds correlation between

- Real refractive index and both size parameters
- Imaginary refractive index and cloud effective variance
- Effective radius and variance

MILAGRO Aerosol over cloud

We use

- 7 RSP channels (410nm, 470nm, 555nm, 670nm, 865nm, 1590nm, and 2250nm)
- ~75 Angular observations between 40° forward (toward the sun) and 20° backwards
- Total number of observations: 525

We assume

- **Cloud**: Uniform size distribution, infinite optical depth, top at 500m
- **Aerosol**: uniformly distributed between 600 and 1800m
- Two parameter model for imaginary refractive index
- Aerosols are spheres

A priori values

- **Cloud**: observations in the rainbow are compared to a Look Up Table of cloud single scattering properties. Standard (gamma) size distribution: $\mathbf{R_{eff,cl}=6.25\mu m}$, $\mathbf{V_{eff,cl}=0.075}$
- **Aerosol**: Mexico City urban-industrial mix AERONET model from Dubovik et al. 2002

Fine mode : $m_f = \mathit{1.47}+0.03i$, $R_{eff,f}=0.136\mu m$, $V_{eff,f}=0.43$, $\tau_f=0.12$

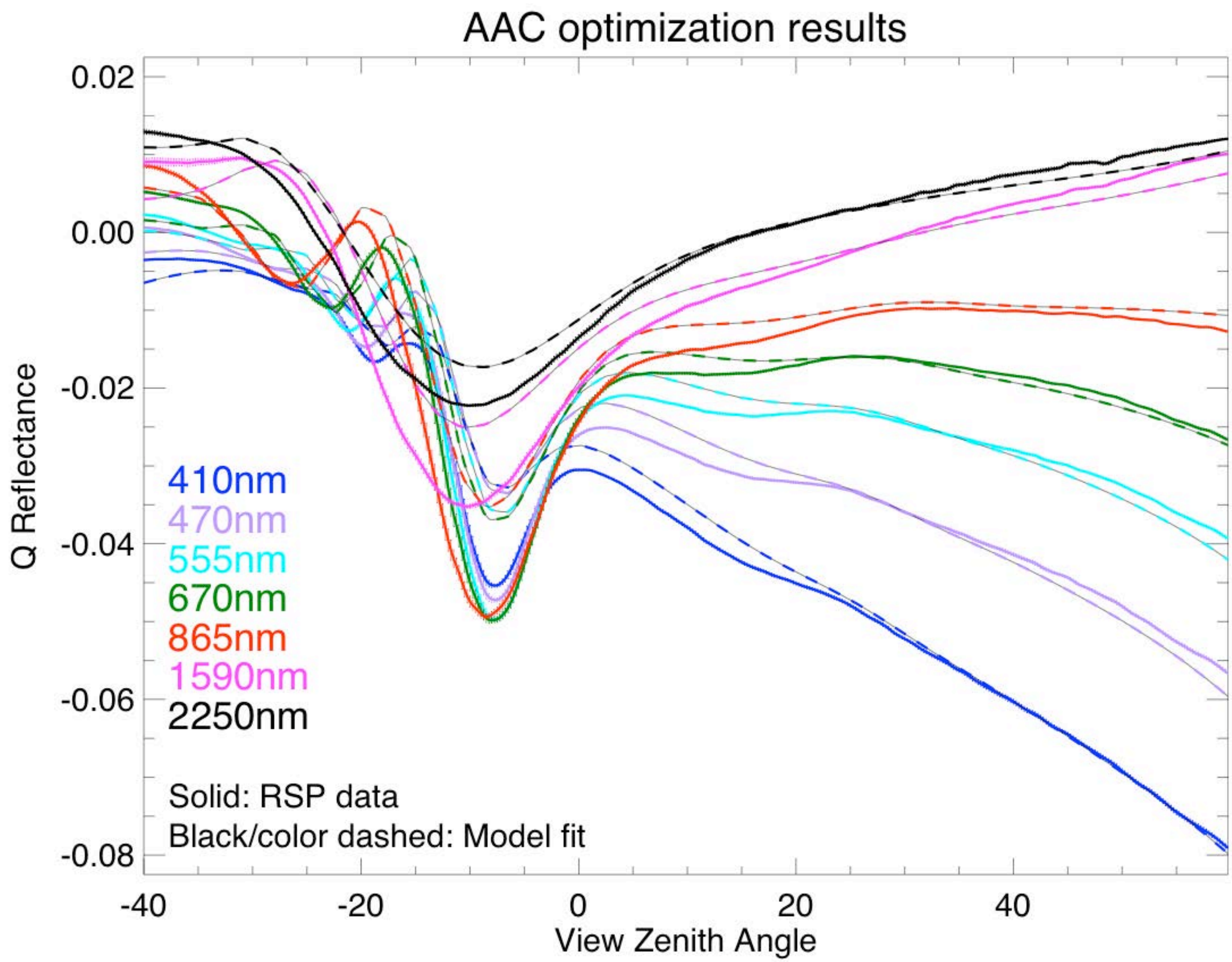
Coarse mode : $\mathit{m_c=1.47+0.03i}$, $\mathit{R_{eff,c}=2.960\mu m}$, $\mathit{V_{eff,c}=0.63}$, $\mathit{\tau_c=0.04}$

m - refractive index
R_{eff} - effective radius [μm]

V_{eff} - effective variance
τ - aerosol optical depth

Note: italicized parameters are held constant - they are assumed

MILAGRO Aerosol over cloud



MILAGRO Aerosol over cloud

Cloud		
Effective Radius [μm]	**6.82**	**± 0.19**
Effective Variance	**0.028**	**± 0.009**
Fine mode Aerosol		
Imaginary Refractive Index	**0.004**	**± 0.077**
Effective Radius [μm]	**0.14**	**± 0.01**
Effective Variance	**0.06**	**± 0.04**
Aerosol Optical Depth, 532nm	**0.10**	**± 0.02**
Derived parameters		
Total Aerosol Optical Thickness, 532nm	**0.14**	**±0.02**
Single Scattering Albedo, 532nm	**0.87**	**±0.45**

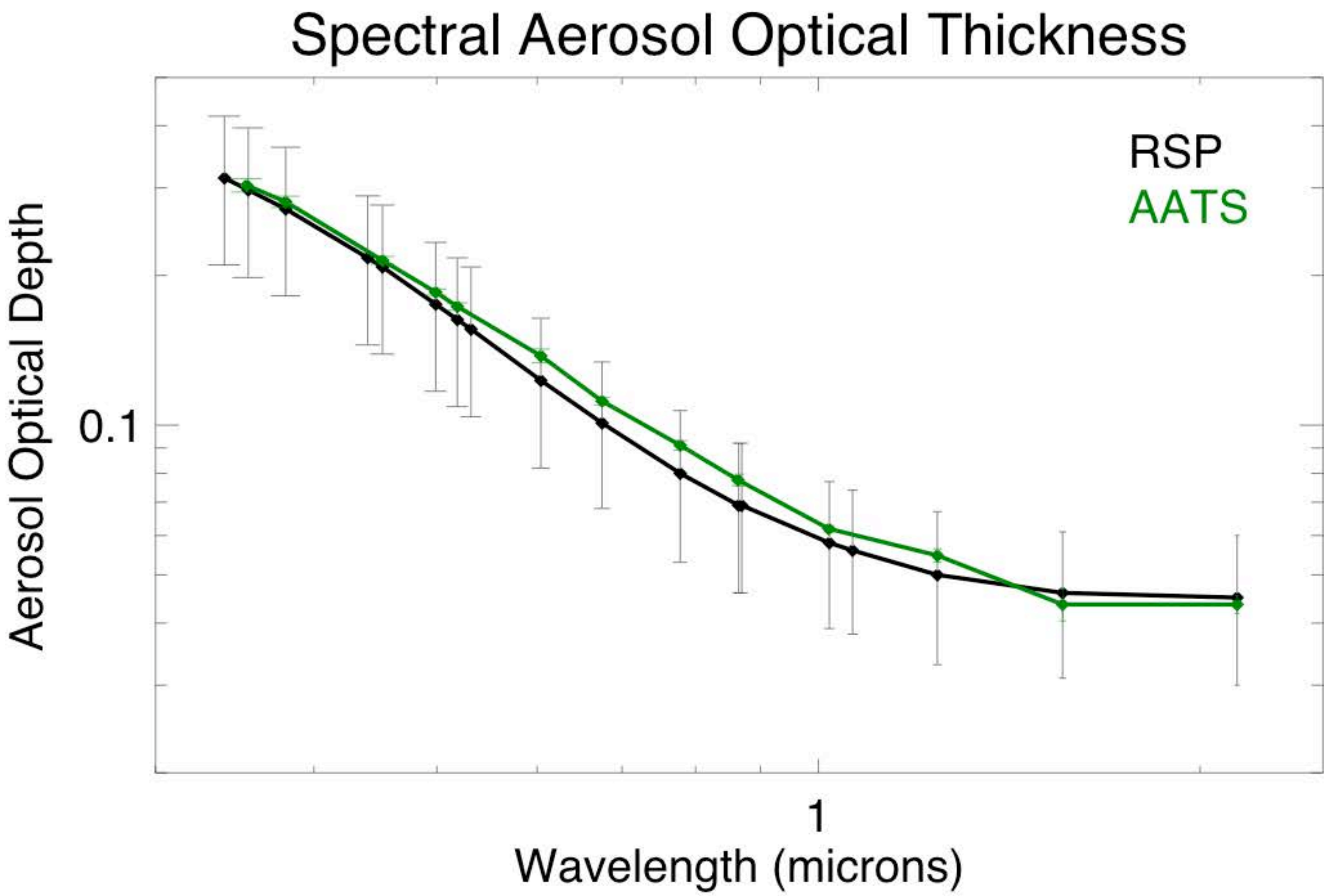
MILAGRO Aerosol over cloud

Cloud		
Effective Radius [μm]	**6.82**	**± 0.19**
Effective Variance	**0.028**	**± 0.009**
Fine mode Aerosol		
Imaginary Refractive Index	**0.004**	**± 0.077**
Effective Radius [μm]	**0.14**	**± 0.01**
Effective Variance	**0.06**	**± 0.04**
Aerosol Optical Depth,	**0.10**	**± 0.02**
Derived parameters		
Total Aerosol Optical Thickness, 532nm	**0.14**	**±0.02**
Single Scattering Albedo, 532nm	**0.87**	**±0.45**

Large error for imaginary refractive index means large single scattering albedo error

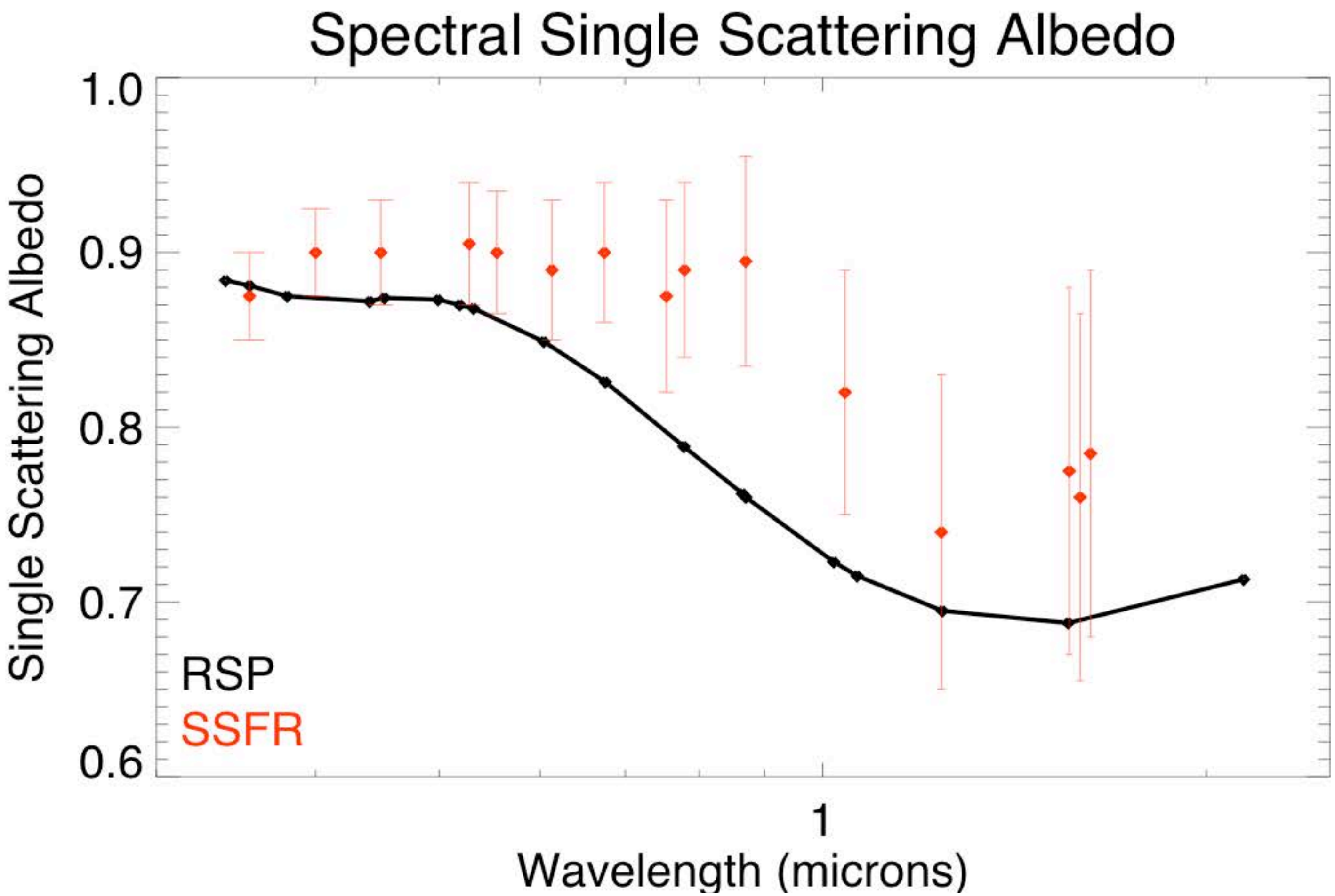
MILAGRO Aerosol over cloud

Results compare well to AATS sun photometer



MILAGRO Aerosol over cloud

Large errors but reasonable comparison to Solar Spectral Flux Radiometer observations*



* R. W. Bergstrom, K. S. Schmidt, O. Coddington, P. Pilewskie, H. Guan, J. M. Livingston, J. Redemann, and P. B. Russell. Aerosol spectral absorption in the mexico city area: results from airborne measurements during milagro/intex b. *Atmos. Chem. Phys.*, 10:6333–6343, 2010.

MILAGRO Aerosol over cloud

Interpretation and Conclusions

- **Fine mode aerosol optical depth** and **size distribution** retrieved **accurately**, as predicted by simulations

- **Fine mode refractive index**, and related **single scattering albedo** has large assessed errors, but is similar to other observations

- **Provided that cloud top height is known,** we can retrieve aerosol optical depth, and to a lesser degree, absorption above clouds

- **Accuracy in the latter increases with optical depth**

Final Conclusions

The climate community needs accurate remote sensing of aerosols

Scanning polarimeters, such as the airborne RSP and soon to be launched APS, hold much promise for aerosol optical property retrieval

To investigate RSP and APS capability:

- Constructed a flexible optimal estimation software package for RSP data (DAO)
- Created a method that uses DAO to determine retrieval capability
- Tested this method using data from two field campaigns, where the observational scenario is “difficult”

Collaborators

- **ARCTAS co-authors:** B. Cairns, M. Ottaviani, R. Ferrare, J. Hair, C. Hostetler, M. Obland, R. Rogers, J. Redemann, Y. Shinozuka, A. Clarke, S. Freitag, S. Howell, V. Kapustin, and C. McNaughton.
- **MILAGRO co-authors**: B. Cairns, J. Redemann, R.W. Bergstrom, and A. Stohl.

I have been the grateful recipient of funding from the National Science Foundation's IGERT fellowship (for my first two years) and from the NASA Glory Project, through my advisor Brian Cairns

And thanks to all of you!